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88

THE INSTITUTION

OF

MECHANICAL ENGINEERS.

ESTABLISHED 1847

PROCEEDINGS.

1898.

PARTS 1–2.

46518/99

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19 VICTORIA STREET, WESTMINSTER, S.W.

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PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861-62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71. (*Deceased* 1897.)

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77. (*Deceased* 1893.)

John Robinson, 1878–79.

Edward A. Cowper, 1880–81. (*Deceased* 1893.)

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Jeremiah Head, 1885–86.

Sir Edward H. Carbutt, Bart., 1887–88.

Charles Cochrane, 1889.

Joseph Tomlinson, 1890–91. (*Deceased* 1894.)

Sir William Anderson, K.C.B., D.C.L., F.R.S., 1892–93.

Alexander B. W. Kennedy, LL.D., F.R.S., 1894–95.

E. Windsor Richards, 1896–97.

The Institution of Mechanical Engineers.

OFFICERS.

1898.

PRESIDENT.

Samuel W. Johnson,	Derby.

PAST-PRESIDENTS.

Sir William Anderson, K.C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
E. Windsor Richards,	Caerleon.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Arthur Keen,	Birmingham.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
Henry Davey,	London.
William Dean,	Swindon.
Sir Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
Edward B. Ellington,	London.
H. Graham Harris,	London.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
William Laird,	Birkenhead.
Henry Lea,	Birmingham.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
T. Hurry Riches,	Cardiff.
John I. Thornycroft, F.R.S.,	London.
A. Tannett Walker,	Leeds.

TREASURER.

Harry Lee Millar.

SECRETARY.

Edgar Worthington,

The Institution of Mechanical Engineers, 19 *Victoria Street*, *Westminster*, *S.W*

[Telegraphic address:—*Mech*, *London.* Telephone:—*Westminster*, 264.]

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

AUGUST 1878.

1st. The name of the Association is "THE INSTITUTION OF MECHANICAL ENGINEERS."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(A.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(B.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(C.) To acquire and dispose of property for the purposes aforesaid.

(D.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

February 1893.

INTRODUCTION.

Whereas an Association called "The Institution of Mechanical Engineers" existed from 1847 to 1878 for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply;

And whereas the Institution was formed in 1878 for furthering and extending the objects of the former Institution, by a registered Association, under the Companies Acts 1862 and 1867;

And whereas terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows :—

CONSTITUTION.

1. For the purpose of registration the number of members of the Institution is unlimited.

MEMBERS, ASSOCIATE MEMBERS, GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

2. The present Members of the Institution, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

4. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

5. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

6. In addition to the persons already admitted as Graduates, Associates, and Honorary Life Members respectively, the Institution may admit such persons as may be qualified and elected in that behalf as Associate Members, Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: provided that no Associate Member, Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

7. The qualification and mode of election of Associate Members, Graduates, Associates, and Honorary Life Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

8. The rights and privileges of every Member, Associate Member, Graduate, Associate, or Honorary Life Member shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. The Entrance Fees and Subscriptions of Members, Associate Members, Graduates, and Associates shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

EXPULSION.

10. If any Member, Associate Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the register by the Council at any time afterwards, and he shall thereupon cease to have any rights as a Member, Associate Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: provided always that this regulation shall not be construed to compel the Council to remove any name, if they shall be satisfied the same ought to be retained.

11. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the register, and he shall thereupon cease to be a Member, Associate Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

12. The General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

13. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

14. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members or Associate Members of the Institution,

specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members or Associate Members of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

15. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every person on the register of the Institution, except as provided by Article 35, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

16. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Associate Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or by any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

17. Twenty Members or Associate Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members or Associate Members shall constitute a quorum for the purpose of a Special Meeting.

18. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

19. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

20. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded; and by a poll, when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman; and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member and Associate Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

21. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: provided that the Chairman may review his decision at the same Meeting, if any error be then pointed out to him.

BY-LAWS.

22. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be substituted or added as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members and Associate Members at an Annual General Meeting, after notice of the proposed alteration or addition has been announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

23. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-Presidents. The President, two Vice-Presidents, and five Members of Council (other than Past-Presidents), shall retire at each Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree among themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

24. The election of a President, Vice-Presidents, and Members of Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

25. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another; and the President, Vice-Presidents, or Members of Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

26. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws, the officers and servants of the Institution shall be appointed and removed by the Council.

27. The powers and duties of the officers of the Institution shall, subject to any express provision in the By-laws, be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

28. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three members of Council shall form a quorum.

29. The Council shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

30. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

31. The Council may, with the authority of a resolution of the Members and Associate Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution, or otherwise at their discretion.

32. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members and Associate Members in General Meeting, shall be afterwards impeached by any member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

33. A notice may be served by the Council upon any Member, Associate Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to him at his registered place of abode.

34. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post; and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

35. No Member, Associate Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom, shall be entitled to any notice; and all proceedings may be had and taken without notice to such member, in the same manner as if he had had due notice.

By-laws.

(*Last Revision, February* 1894.)

MEMBERSHIP.

1. Candidates for admission as Members must be persons not under twenty-five years of age, who, having occupied during a sufficient period a responsible position in connection with the practice or science of Engineering, may be considered by the Council to be qualified for election.

2. Candidates for admission as Associate Members must be persons not under twenty-five years of age, who, being engaged in such work as is connected with the practice or science of Engineering, may be considered by the Council to be qualified for election, though not yet to occupy positions of sufficient responsibility, or otherwise not yet to be eligible, for admission as Members. They may afterwards be transferred at the discretion of the Council to the class of Members.

3. Candidates for admission as Graduates must be persons holding subordinate situations, and not under eighteen years of age. They must furnish evidence of training in the principles as well as in the practice of Engineering. Before attaining the age of twenty-six years, those elected after 1892 must apply for election as Members, Associate Members, or Associates, if they desire to remain connected with the Institution; they may not continue Graduates after attaining the age of twenty-six.

4. Candidates for admission as Associates must be persons not under twenty-five years of age, who from their scientific attainments or position in society may be considered eligible by the Council. They may afterwards be transferred at the discretion of the Council to the class of Associate Members or of Members.

5. The Council shall have the power to nominate as Honorary Life Members persons of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Associate Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings; but Members and Associate Members only shall be entitled to vote thereat.

7. The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Associate Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Associate Members, A. M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E.

8. Subject to such regulations as the Council may from time to time prescribe, any Member, Associate Member, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution.

ENTRANCE FEES AND SUBSCRIPTIONS.

9. Each Member shall pay an Annual Subscription of £3, and on election an Entrance Fee of £2.

10. Each Associate Member shall pay an Annual Subscription of £2 10*s*., and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Members, he shall pay on transference 10*s*. additional subscription for the current year, and £1 additional entrance fee.

11. Each Graduate shall pay an Annual Subscription of £1 10*s*., but no Entrance Fee. Any Graduate elected prior to 1893, if transferred by the Council to the class of Associate Members, shall pay on transference £1 additional subscription for the current year, but no additional entrance fee; if transferred direct to the class of Members, he shall pay on transference £1 10*s*. additional subscription for the current year, and £1 additional entrance fee.

12. Each Associate shall pay an Annual Subscription of £2 10*s.*, and on election an Entrance Fee of £1. If afterwards transferred by the Council to the class of Associate Members, he shall pay on transference no additional subscription or entrance fee. If transferred direct to the class of Members, he shall pay on transference 10*s.* additional subscription for the current year, and £1 additional entrance fee; except Associates elected prior to 1893, who shall pay no additional entrance fee on transference.

13. All subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first subscription of Members, Associate Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

14. In the case of Members, Associate Members, Graduates, or Associates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

15. Any Member, Associate Member, or Associate, whose subscription is not in arrear, may at any time compound for his subscription for the current and all future years by the payment of Fifty Pounds, if paid in any one of the first five years of his membership. If paid subsequently, the sum of Fifty Pounds shall be reduced by One Pound per annum for every year of membership after five years. All compositions shall be deemed to be capital moneys of the Institution.

16. The Council may at their discretion reduce or remit the annual subscription, or the arrears of annual subscription, of any Member or Associate Member who shall have been a subscribing member of the Institution for twenty years, and shall have become unable to continue the annual subscription provided by these By-laws.

17. No Proceedings or Ballot Lists or Certificates shall be sent to Members, Associate Members, Graduates, or Associates, who are in

arrear with their subscriptions more than twelve months, and whose subscriptions have not been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, ASSOCIATE MEMBERS, GRADUATES, AND ASSOCIATES.

18. A recommendation for admission according to Form A or B in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members or Associate Members if the application be for admission as a Member or Associate Member or Associate, and by three Members or Associate Members if it be for a Graduate.

19. All elections shall take place by ballot, four-fifths of the votes given being necessary for election.

20. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members and Associate Members. The name of any Candidate approved by the Council for admission as an Associate Member or an Associate shall not be inserted in the ballot list until he has signed the Form C in the Appendix. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

21. The Elections shall take place at the General Meetings only.

22. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form D; but his name shall not be added to the register of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form E in the Appendix.

23. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

24. An Associate Member desirous of being transferred to the class of Members, or an Associate to the class of Associate Members or of Members, shall forward to the Secretary a recommendation according to Form F in the Appendix, signed by not less than five Members or Associate Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form G; but his name shall not be added to the list of Members or Associate Members until he shall have signed the Form H, and shall have paid the additional entrance fee (if any), and the additional subscription (if any) for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

25. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member or Associate Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members and Associate Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

26. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members and Associate Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

27. The Secretary of the Institution shall be appointed, as and when a vacancy occurs, by the Members and Associate Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

28. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

29. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council; or, if so directed by the Council, shall be printed in the Proceedings without having been read at a General Meeting.

30. All books, drawings, communications, &c., shall be accessible to the members of the Institution at all reasonable times.

31. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

32. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

33. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

34. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members Associate Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or by the Author with the consent of the Council.

35. Each Member or Associate Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member or Associate Member asks that this shall be done.

36. Every Member, Associate Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

37. The President shall ex officio be member of all Committees of Council.

38. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

39. The Council shall present the yearly accounts to the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members and Associate Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members and Associate Members.

40. Any member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

41. At any Meeting of the Institution any member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being years of age, and desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the three other signers from trustworthy information, propose and recommend him as a proper person to belong to the Institution.

Witness our hands, this day of

Members or Associate Members.

FORM B.

Mr. born on being desirous of admission into The Institution of Mechanical Engineers, we, the undersigned proposer and seconder from our personal knowledge, and the other signer or signers from trustworthy information, propose and recommend him as a proper person to become a Graduate thereof.

Witness our hands, this day of

Members or Associate Members.

FORM C.

If elected an of The Institution of Mechanical Engineers, I, the undersigned, do hereby engage to ratify my election by signing the form of agreement and paying the entrance fee and annual subscription in conformity with the By-laws.

Witness my hand, this day of

FORM D.

Sir,—I have to inform you that on the you were elected a of The Institution of Mechanical Engineers. For the ratification of your election in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM E.

I, the undersigned, being elected a of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM F.

Mr. being years of age, and desirous of being transferred into the class of of The Institution of Mechanical Engineers, we, the undersigned, from our personal knowledge recommend him as a proper person to be so transferred by the Council.

Witness our hands, this day of

Members or Associate Members.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of of The Institution of Mechanical Engineers. For the ratification of your transference in conformity with the rules, it is requisite that the enclosed form be returned to me with your signature, and that your additional Entrance Fee and additional Annual Subscription for the current year be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the transference will become void.

I am, Sir, Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of of The Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

The Institution of Mechanical Engineers.

PROCEEDINGS.

February 1898.

The Fifty-first Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 10th February 1898, at Half-past Seven o'clock p.m.; E. Windsor Richards, Esq., Retiring President, in the chair, succeeded by Samuel W. Johnson, Esq., President elected at the Meeting.

The President had great pleasure in introducing to the Members the newly elected Secretary, Mr. Edgar Worthington. He desired to express the hope that his connection with the Institution would be long and pleasant, and would result not only to his advantage but to the interests of the Institution.

Mr. Edgar Worthington had very great pleasure in acknowledging the welcome accorded to him by the President and Members, as Secretary of the Institution of Mechanical Engineers. He felt he was venturing to tread in footsteps which had been so well filled in the past that he might find a difficulty in quite filling them in the same way; but he would do everything in his power to study the interests of the Institution. Already he enjoyed the acquaintance of a number of the Members, and he trusted as time went on that he should become acquainted with them all, one by one, when they called at the present offices of the Institution, and still more extensively at the new building when it was completed. He thanked them all very much for the honour they had done him.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following fifty-three candidates were found to be duly elected:—

MEMBERS.

Akers, Charles Henry,	Guatemala.
Attwood, Jabez,	Stourbridge.
Burt, George,	London.
Greaven, Louis,	Buenos Aires.
Green, Thomas Willoughby,	Leeds.
Grover, Frederick,	Leeds.
Houghton, Reginald James,	Widnes.
Maitland, Cree,	Port Dickson.
Morris, John,	Salford.
Pettigrew, William Frank,	Barrow-in-Furness.
Reynolds, William Fleck,	Belfast.
Row, Oliver Matthews,	Manchester.
Royce, Frederick Henry,	Manchester.
Stevens, Arthur James,	Newport, Mon.
Stirling, Robert,	Tocopilla, Chile.
Wood, Sydney Henry,	London.

ASSOCIATE MEMBERS.

Bartle, George William,	London.
Bradley, Godfrey Thomas,	Hull.
Donald, David Boswell,	Penryn.
Fowler, Percy Merwood,	Johannesburg.
Golding, Henry Albert,	London.
Gordon, James,	London.
Hill, Joseph,	London.
Hirst, George Frederick,	Rotherham.
Hughes, George Henry,	London.
Jackson, Ernest,	Kendal.
Jackson, Harry Loxton,	Bolton.

Larmuth, William Oliver,	Salford.
Oldham, Harry George Vincent,	London.
Rodda, Joseph Tonkin,	Eastbourne.
Shiels, James,	Karachi.
Urquhart, Ridley James,	Liverpool.
Wigglesworth, Frank,	Bradford, Yorks.
Wilson, Daniel Ellis,	London.
Wilson, John Charles,	Nottingham.

ASSOCIATES.

Beanland, Fred,	Leeds.
Light, George Miller,	London.
Marshall, Percival,	London.
Wimpenny, Abel Buckley,	Stockport.

GRADUATES.

Balch, Bertram Duthoit,	Kingston-on-Thames.
Bruce, John George,	Gateshead.
Ellison, John,	Bradford, Yorks.
Goodbehere, Alwyn,	Manchester.
Goodbehere, Eric,	Manchester.
Homan, Brees van,	London.
Kenrick, Archibald, Jun.,	Leeds.
Roberts, Herbert Edward,	London.
Sharp, William,	Bradford, Yorks.
Stanley, Harry Frank, Jun.,	London.
Taylor, Charles Percy,	Northfleet.
Turner, Vincent,	Wolverhampton.
Tyley, Frederick John,	London.
Williams, Norman C.,	London.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1898.

The past year 1897 having been the jubilee of the establishment of the Institution in 1847, the Annual Report of the Council might appropriately have commenced on this occasion with a concise review of its history during the half century of its existence, had not such a review been already embodied in the Address delivered by the President at the Summer Meeting held in Birmingham, wherein he recounted the origin of the Institution, and traced the leading features of its growth and progress under the successive Presidents, of whom the list is headed by George Stephenson. Included also in the Address were statistics, to which the following Report of the business and progress during 1897 forms an immediate sequel.

At the end of last year the number of names in all classes on the roll of the Institution was 2,493, as compared with 2,359 at the end of the previous year, showing a net gain of 134. During 1897 there were added to the register 224 names; against which the loss by decease was 30, and by resignation or removal 60.

During 1897 the following distinctions have been conferred by the Queen upon Members of this Institution. The Right Honourable W. J. Pirrie, Lord Mayor of Belfast for a second year, has been appointed a member of Her Majesty's Most Honourable Privy Council in Ireland. Sir Alexander Wilson, Bart., and Sir Lindsay Wood, Bart., have been made Baronets. Sir William Anderson, K.C.B., Past-President, and Sir John Wolfe Barry, K.C.B., have each been created a Knight Commander of the Bath. Sir Alexander R. Binnie, Sir Benjamin A. Dobson, Member of Council, and Sir Thomas Richardson, M.P., have received the honour of knighthood. To each gentleman the Council have had the pleasure of offering their congratulations on behalf of the Institution.

In recognition of the large amount of time and labour so freely devoted by Professor W. C. Roberts-Austen, C.B., D.C.L., F.R.S., to the work of the Alloys Research, and the highly valuable practical results he has already realised for the benefit of Mechanical Engineers and of the manifold industries associated with engineering, the Council have enrolled his name as an Honorary Life Member of the Institution, feeling assured that this step will be cordially welcomed by the whole of the Members.

The following seventeen Transferences have been made by the Council in 1897 :—

To the class of Members.

BROMLY, ALFRED HAMMOND,	Associate Member	Colchester.
COLLIS, ALFRED EDWARD,	do.	Lincoln.
DUNN, MATTHEW,	do.	Selby.
FOWLER, HENRY,	do.	Horwich.
NASMITH, JOSEPH,	do.	Manchester.
STOCKTON, JOSEPH SADLER,	do.	Kenilworth.
STONE, SIDNEY,	do.	Birmingham.
WEST, CHARLES HERBERT,	do.	Liverpool.
CHALLEN, WALTER BERNARD,	Graduate	Birmingham.
HOSGOOD, WALTER JAMES,	do.	Cardiff.

To the class of Associate Members.

BENTLEY, WALLACE,	Associate	Halifax.
ADAMS, SIDNEY RICKMAN,	Graduate	Johannesburg.
BELL, WILLIAM THOMAS,	do.	Lincoln.
BULWER, ERNEST HENRY EARLE,	do.	London.
GARRETT, FRANK, JUN.,	do.	Leiston.
JOY, BASIL HUMBERT,	do.	London.
REDFERN, CHARLES GEORGE,	do.	London.

The following thirty-two Deceases of Members of the Institution have occurred during the past year :—

ALLPORT, CHARLES JAMES,	London.
ARCHBOLD, JOHN,	Eastwood.
BARRETT, JOHN JAMES,	Bombay.
BLECHYNDEN, ALFRED,	London.

Carr, Robert,	London.
Fletcher, George,	Derby.
Fletcher, Lavington Evans,	Manchester.
Fogg, Robert,	London.
Grew, Nathaniel,	London.
Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., (Honorary Life Member)	Dublin.
Houghton, Francis Gassiot,	London.
Hulse, William Wilson,	Manchester.
Irwin, Thomas Frederick,	Liverpool.
Kelson, Frederick Colthurst,	Liverpool.
Kennedy, John Pitt.	London.
Lewis, Henry Watkin,	Abercanaid.
Lowe, John Edgar,	London.
Marsden, Benjamin,	Manchester.
Marsh, Henry William,	Bristol.
Morgan, Thomas Rees,	Alliance, Ohio.
Platt, James,	Gloucester.
Putnam, William,	Darlington.
Quirk, Edward,	London.
Ramsbottom, John,	Alderley Edge.
Rapier, Richard Christopher,	London.
Ruston, Joseph,	Lincoln.
Sacré, Alfred Louis,	London.
Scott, Frank Walter,	London.
Smith, Charles Hubert,	Leith.
Smith, Sir John,	Derby.
Stewart, John,	London.
Tasker, Frederick,	Sheffield.

Of these Mr. Ramsbottom was one of the original Members who joined in constituting the Institution at its establishment on 27th January 1847; for a number of years he was a Member of Council and a Vice-President, and he occupied the position of President in 1870 and 1871. Mr. Platt, who joined the Institution in 1871, was a Member of Council from 1893.

The following twenty-five gentlemen have ceased to be Members of the Institution during the past year:—

Baird, George,	Slough.
Balmokand, Rai Bahadur,	Lahore.

Church, Harry (Graduate),	Entre Rios.
Crighton, John,	Manchester.
Donald, James,	Barrow-in-Furness.
Ellis, Joseph S.,	Chepstow.
Firth, George Henry,	Bradford.
Grenville, Robert Neville,	Glastonbury.
Hall, John Francis,	Sheffield.
Hedley, Thomas (Graduate),	Portland, U.S.
Hibbert, George,	Gateshead.
Hornbrook, Raymond Hillman,	San Francisco.
Machado, Dr. Antonio Augusto,	Bahia.
Martin, Henry James,	Swansea.
Muir, Edwin,	Manchester.
Nicholson, Thomas,	Glasgow.
Paton, Robert J.,	Campinas, Brazil.
Poppleton, Clement Francis (Associate Member),	London.
Tilley, Albert,	Wishaw.
Wakefield, William Marsden (Graduate),	Calcutta.
Wilson, Thomas,	Iquique.
Wormald, Henry,	Pontefract.
Wrench, John Henry Kirke (Graduate),	Chicago.
Wylde, Thomas,	Johannesburg.
Wylie, James,	Nottingham.

In addition to these there have been thirty-five Resignations of membership.

The Accounts for the year ending 31 December 1897 are now submitted to the Members (see pages 14–17) after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £7,656 5*s.* 5*d.*, while the expenditure, actual and estimated, was £6,202 8*s.* 3*d.*, leaving a balance of receipts over expenditure of £1,453 17*s.* 2*d.* available for sinking fund. The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £72,329 12*s.* 1*d.*; and deducting therefrom the £25,000 of debentures, and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £46,729 12*s.* 1*d.*

Of this sum £2,500 has been set aside as a sinking fund for the redemption of the debentures, leaving the unappropriated balance of £44,229 12*s.* 1*d.*, as stated in the balance sheet. The sum of £35,893, as seen from the balance sheet, still remains invested in Railway Debenture and India Stocks and Consols, registered in the name of the Institution, while £30,436 0*s.* 9*d.* has already been expended on account of the Institution House. The certificates of the whole of the securities have been duly audited by the Finance Committee and the auditor.

The building of the Institution House at Storey's Gate, Westminster, which has been proceeded with during the past year, has been somewhat delayed in connection with various negociations arising during its progress, with respect to questions of ancient lights &c. which have now been satisfactorily arranged. Debentures of £100 each, to the amount of £25,000, bearing interest at the rate of four per cent., have been issued to the seventy-five Members who applied for them; the greater part of this amount has been temporarily invested in Consols, pending its being required for meeting the payments on the House account.

For the Research Committee on the Value of the Steam-Jacket, under the chairmanship of Mr. Henry Davey, a considerable number of experiments have been carried out during the year at University College, London, by Professor Beare, with the special apparatus designed by the Committee. The results are being tabulated, and it is hoped that some definite conclusions as to the laws governing initial condensation in steam cylinders will be obtained from them.

The Alloys Research Committee, of which Sir William Anderson is the chairman, received a year ago from Professor Roberts-Austen his Fourth Report, which was read and discussed at the last Annual General Meeting. Since then the further prosecution of the research has been continuously carried on; and the hope is held out that the next Report, dealing almost entirely with the properties and use of Steel, may be sufficiently advanced for presentation in the course of the current year.

The First Report to the Gas-Engine Research Committee, under the chairmanship of Professor Kennedy, has been received from Professor Burstall, containing a description of the apparatus and methods employed and the preliminary results obtained. It is announced for reading and discussion at the present meeting.

The work of the Steam-Engine Research Committee, of which Mr. Bryan Donkin is the chairman, has been waiting for a steam engine to be made, suitable for experimental purposes. A compound engine with surface condenser has been decided upon, and is ordered; it is hoped it will be ready for experiments to be started in a few months.

For the additions to the Library of the Institution which have been received by presentation and exchange during the past year, as enumerated in pages 20–29, the Council here record their thanks to the several Donors. A valuable donation of great historical interest, received from Mr. John Etherington, consists of eight handsome volumes comprising the Reports to the Crown, the Jury Reports, and the Official Catalogue, of the Exhibition of 1851, being the identical set originally presented by H.M. Commissioners to Mr. J. Scott Russell. The restricted library accommodation hitherto available in the present offices of the Institution will during the coming year be succeeded by the ampler space provided in the new building. The Council therefore look forwards to this enlargement as a peculiarly favourable opportunity for welcoming from Members who have published works valuable for reference, or original pamphlets on engineering subjects, or records of experiments, copies of such publications for permanent preservation, and for enhancing the value of the expanding Library.

The General Meetings in 1897 were the Annual General Meeting and the Spring Meeting, both held in London; the Summer Meeting in Birmingham; and the Autumn Meeting in London. Altogether eight sittings were occupied in the reading and discussion of the following Papers, which are published in the Proceedings:—

Fourth Report to the Alloys Research Committee; by Professor W. C. Roberts-Austen, C.B., F.R.S.
Partially Immersed Screw-Propellers for Canal Boats, and the influence of Section of Waterway; by Mr. Henry Barcroft.
Mechanical Propulsion on Canals; by Mr. Leslie S. Robinson.
Address by the President, E. Windsor Richards, Esq.
Some points in Cycle Construction; by Mr. F. J. Osmond.
The City of Birmingham Corporation Water Works; by Mr. Henry Davey.
High-Speed Self-Lubricating Steam-Engines; by Mr. Alfred Morcom.
Experiments upon Propeller Ventilating Fans, and upon the Electric Motor driving them; by Mr. William George Walker.
Diagram Accounts for Engineering Work; by Mr. John Jameson.

The attendances during 1897 were as follows:—at the Annual General Meeting 88 Members and 78 Visitors; at the Spring Meeting 63 Members and 70 Visitors; at the Summer Meeting 405 Members and 75 Visitors; and at the Autumn Meeting 89 Members and 81 Visitors.

After an interval of twenty-one years the Summer Meeting was held in Birmingham, the birthplace of the Institution half a century ago. The President's Address, reviewing the origin and history of the Institution, was followed by a paper dealing with some points in cycle construction, which has risen to so important a position among the leading manufactures of the city and the surrounding district. The meagre discussion that ensued may possibly be accounted for by the consideration that the keenness of the competition in this industry may have induced a reticence on the part of other makers, with which the author's frank presentation of his views and experience stands in all the more favourable contrast. By way of compensation the Members enjoyed the advantage of visiting numerous cycle works, which were freely opened to their inspection by the author and other cycle makers. The exceptional conditions affecting the maintenance of an adequate supply of water to the city by pumping, pending the completion of a gravitation supply from Radnorshire, furnished the opportunity for an interesting paper on the Corporation Water Works, setting forth these peculiar conditions and explaining the way in which they are being met. A description of quick-revolution self-lubricating engines led to a discussion extending to such length as to limit to three the number of papers that could be read at the meeting; and its interest was enhanced by the handsome invitation of the makers to visit their works—a privilege which was highly appreciated and heartily acknowledged. Visits and excursions to numerous other engineering and manufacturing works and other establishments, both in Birmingham and the neighbourhood, and in Wolverhampton, Walsall, Coventry, and Rugby, afforded an insight into a large variety of industries, for which mechanical appliances have been more and more extensively resorted to. The programme of the arrangements for the meeting was drawn up by the active members of a local Committee, under the chairmanship of Mr. Arthur Keen; in addition to the foregoing excursions and visits to works, it included an excursion to places of Shakespearian interest in Stratford-on-Avon and the neighbourhood, a visit to Warwick Castle and Guy's Cliff, and an invitation by the Committee to a Conversazione in the Botanical Gardens, Edgbaston. To each Member attending the meeting a memento of the Jubilee of the Institution was presented by the Committee, in the form of a medal bearing on the obverse the head of George Stephenson, the first President of the Institution, and on the reverse the arms of the city of Birmingham. The work of giving effect to the details of the programme was undertaken and ably carried out by Mr. W. Bayley Marshall and Mr. Eric M. Carter as joint Honorary Secretaries; and the Council have marked their appreciation of their active exertions by presenting to each on behalf of the Members a silver salver with an inscription recording their grateful acknowledgment of the obliging services they rendered for this Jubilee Meeting of the Institution.

As already announced at the Birmingham Meeting, owing to somewhat impaired strength Mr. Alfred Bache is now about to retire from his present duties, after having spent forty-three years in the service of the Institution, the last fourteen as Secretary; and at the recent Autumn Meeting Mr. Edgar Worthington was appointed by the Members, on the recommendation of the Council, to succeed to the secretaryship.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of the Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting. In view of the nomination made at the last Meeting for the Presidency, the Council purpose holding this year's Summer Meeting of the Institution in Derby.

STATEMENT OF ACCOUNTS
AND BALANCE SHEET
FOR THE YEAR 1897.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1897	1,008	2	0			
Less Authors' Copies of Papers, repaid	38	6	0	969	16	0
„ Printing Library Catalogue				120	9	6
„ Stationery and General Printing				252	17	3
„ Binding				44	9	7
„ Rent of Offices				710	0	0
„ Salaries and Wages				2,166	11	0
„ Coal, Firewood, and Lighting				45	4	5
„ Fittings and Repairs				62	15	6
„ Postages, Telegrams, and Telephone				283	0	3
„ Insurance				7	0	6
„ Travelling Expenses				21	0	8
„ Law Charges				4	1	0
„ Petty Expenses				54	8	10
„ Meeting Expenses—						
Printing	184	13	0			
Reporting	45	3	8			
Diagrams, Screen, &c.	162	1	3			
Travelling and Incidental Expenses	198	14	8	590	12	7
„ Dinner Guests				95	8	7
„ Research				216	17	4
„ Books purchased				4	15	7
„ Willans Premium Fund, moiety of Law Charges				3	14	0
„ Debenture Interest accrued 31st December 1897, and paid				500	0	0
„ Expenses of Issue of Debentures				49	5	8
				6,202	8	3
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	600	0	0	0	0	0
Balance, being excess of Receipts over Expenditure, carried down—				1,453	17	2
				£7,656	5	5

	£	s.	d.	£	s.	d.
To House for Institution—						
Expended on Building this year	12,708	7	4			
Ground Rent during construction	850	8	1	13,558	15	5
To Investment—						
£20,000 Consols 2¾ %				22,612	11	0
Cash Balance 31st December 1897				4,052	11	4
				£40,223	17	9

FOR THE YEAR ENDING 31ST DECEMBER 1897. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
99 *New Members at £2*	198	0	0			
84 *New Associate Members at £1*	84	0	0			
10 *New Associates at £1*	10	0	0			
8 *Associate Members transferred to Members at £1*	8	0	0			
2 *Graduates transferred to Members at £1*	2	0	0	302	0	0
„ Subscriptions for 1897—						
1713 *Members at £3*	5,139	0	0			
271 *Associate Members at £2 10s.*	677	10	0			
70 *Associates at £2 10s.*	175	0	0			
159 *Graduates at £1 10s.*	238	10	0			
8 *Associate Members transferred to Members at 10s.*	4	0	0			
2 *Graduates transferred to Members at £1 10s.*	3	0	0			
6 *Graduates transferred to Associate Members at £1*	6	0	0	6,243	0	0
„ Subscriptions in arrear—						
83 *Members at £3*	249	0	0			
1 *Member, instalment*	2	0	0			
8 *Associate Members at £2 10s.*	20	0	0			
1 *Associate at £2 10s.*	2	10	0			
10 *Graduates at £1 10s.*	15	0	0	288	10	0
„ Subscriptions in advance—						
33 *Members at £3*	99	0	0			
1 *Associate Member at £2 10s.*	2	10	0			
6 *Graduates at £1 10s.*	9	0	0	110	10	0
„ Interest—						
From Investments	608	1	11			
From Bank	59	6	0	667	7	11
„ Reports of Proceedings—						
Extra Copies sold				44	17	6
				£7,656	5	5

	£	s.	d.
By Balance brought down	1,453	17	2
By Life Compositions	250	0	0
By Sale of Investments	10,326	8	9
By Issue of 250 Debentures of £100 each at 4%	25,000	0	0
Cash Balance 31st December 1896	3,193	11	10
	£40,223	17	9

Dr. BALANCE SHEET

	£	s.	d.
To Debentures—			
250 of £100 each at 4%, redeemable in 1917, or at par at any date after 1st Jan. 1908, on six months' notice to holder	25,000	0	0
,, Sinking Fund—			
Amount set aside this year and invested for redemption of Debentures	2,500	0	0
,, Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date (exclusive of back numbers of Proceedings, which cost £5,150)	44,229	12	1
	£72,329	12	1

Signed by the following members of the Finance Committee:—

JEREMIAH HEAD,
DOUGLAS GALTON, BRYAN DONKIN,
WILLIAM H. MAW, JOHN G. MAIR-RUMLEY.

AS AT 31st DECEMBER 1897. *Cr.*

	£	s.	d.	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*				1,000	0	0			
,, ,, ,, *on Current account* . .				2,552	11	4			
In London Joint Stock Bank	389	8	5						
In hand { *expended since closing accounts* }	110	11	7	500	0	0	4,052	11	4
,, Investments—(*cost* £32,183 14*s.* 1*d.*)									
£									
4,237 *London and North Western Ry.* 3% *Debenture Stock*									
3,288 *Midland Railway* ,, ,, ,,									
4,053 *India* 3% *Stock*									
20,000 *Consols* 2¾%									
The Market Value of these investments at 31st Dec. 1897 was about . .							35,893	0	0
,, Subscriptions in Arrear, probable value							265	0	0
,, Office Furniture and Fittings							343	0	0
,, Library							1,240	0	0
,, Drawings, Engravings, Models, Specimens, and Sculpture .							100	0	0
,, Proceedings, back numbers, cost £5,150									
,, House for Institution, expenditure to date							30,436	0	9
							£72,329	12	1

Audited and Certified by

ROBERT A. McLEAN, F.C.A.,
Auditor,
1 Queen Victoria Street, London, E.C.

WILLANS PREMIUM FUND.

		£	s.	d.
Investment £159 8*s*. 5*d*. of India 3% Stock	cost	165	5	0
Law Charges, paid jointly by the two trustee Institutions . . .		7	8	0
Amount held in trust by The Institution of Mechanical Engineers—				
Interest received during 1895		2	7	8
,, ,, ,, 1896		4	15	4
,, ,, ,, 1897		4	15	4
Audited, certified, and signed by the names on pages 16-17.		£11	18	4

DECLARATION OF TRUST

OF THE WILLANS PREMIUM FUND.

To all to whom these presents shall come The Institution of Mechanical Engineers and The Institution of Electrical Engineers send greeting. Whereas a Fund has been subscribed by the friends of the late PETER WILLIAM WILLANS, of Thames Ditton, for the purpose of commemorating his name and the services which he rendered to Engineering and Electrical science; and at the request of the subscribers to the said fund the above-named Institutions have agreed to act as joint Trustees thereof, and the sum of One hundred and sixty-five pounds has accordingly been paid to the said Institutions: now these presents witness that the said Institutions do hereby declare the Trusts upon which they hold the said fund to be as follows:—

1. To invest the said fund upon such securities as trustees are by law authorised to hold, and in such names as the Councils of the two Institutions shall from time to time direct.

2. To apply the proceeds of the said investment as and when received, after payment of any expenses incidental to the administration of the trust, to the Premium hereinafter described, to be known as "the Willans Premium."

3. The Willans Premium shall be awarded alternately by the Council of each of the above-mentioned Institutions; and first by The Institution of Electrical Engineers in December 1897.

4. The Council of the awarding Institution in each alternate period shall award the Willans Premium for the best original paper communicated to their Institution, dealing with such a general subject as the utilisation or transformation of energy, treated especially from the point of view of efficiency or economy: provided that the Premium shall not be awarded unless a paper of sufficient merit in the judgment of the awarding Council shall have been so communicated since the preceding award of that Council.

5. The Premium shall be awarded triennially in and after December 1897, unless otherwise determined by resolution of the respective Councils of the two Institutions.

6. The Premium may be awarded either in money or books or medal, or in any other form which in the instance of any individual award the awarding Council may then determine.

7. In case of no award at the end of any triennial period, the premium available for that award shall be added to the capital of the fund.

In witness whereof The Institution of Mechanical Engineers have hereunto affixed their common seal, and the President and Secretary of The Institution of Electrical Engineers have hereunto set their hands, this sixteenth day of January 1895.

The Seal of The Institution of Mechanical Engineers was impressed by the President in the presence of Alfred Bache, Secretary; and the document was signed as follows:—

ALEXANDER B. W. KENNEDY,
President of The Institution of Mechanical Engineers.
R. E. CROMPTON,
President of The Institution of Electrical Engineers.
F. H. Webb, Secretary of The Institution of Electrical Engineers.

LIST OF DONATIONS TO LIBRARY.

Reports to the Crown, Jury Reports (4 vols.), and Official Catalogue (3 vols.), of the Exhibition of 1851; from Mr. John Etherington.

Transformer Design, by George Adams; from the author.

Proposed Jungfrau Railway; from Mr. Guyer-Zeller.

Traité des Machines à Vapeur, by F. Sinigaglia; from the author.

Marine Engineers and how to become one, by E. G. Constantine; from the author.

Chronology of Inland Navigation in Great Britain, by H. R. de Salis; from the author.

Electric Movement in Air and Water, with theoretical inferences, by Lord Armstrong; from the author.

Electric Railways and Tramways, their construction and operation, by Philip Dawson; from the author.

Railway Engineering, Mechanical and Electrical, by J. W. C. Haldane; from the author.

Steamships and their Machinery from first to last, by J. W. C. Haldane; from the author.

Handbook for Mechanical Engineers, by Henry Adams; from the author.

Edwards' Air-Pump, by Frederick Edwards; from the author.

Royal Institute of Engineers, Holland, Jubilee Memorial Volume; from the Institute.

Festschrift über die Thätigkeit des Vereins Deutscher Eisenbahn-Verwaltungen in den ersten 50 Jahren seines Bestehens, 1846–1896; from the Association.

Eight Hours for Work, by John Rae; from the publishers.

The case against Picketing, by W. J. Shaxby; from Mr. John Etherington.

The Engineers' Strike; from "Engineering."

Indicator Diagrams and Engine and Boiler Testing, by Charles Day; from the author.

Experiments on Steam Boilers, by Bryan Donkin and Alexander B. W. Kennedy; from "Engineering."

Notes et Formules de l'Ingénieur, 1898; from the publishers.

Progress in Printing and the Graphic Arts during the Victorian Era, by John Southward; from the author.

University College, Sheffield, Commemoration Volume; from the College.

The Principles of Waterworks Engineering, by J. H. T. Tudsbery and A. W. Brightmore; from the authors.

Register Book of the British Corporation for the Survey and Registry of Shipping; from the Corporation.

Law of Trade-marks, Trade-names, and Merchandise marks, by D. M. Kerly; from Mr. M. H. Butcher.

Map of the Siberian Railway, with Key; from Mr. W. G. Walker.

Electrical Traction, by Ernest Wilson; from the publisher.

Cours de Mécanique appliquée aux machines—Locomotives et Machines Marines; from the publishers.

Report of the Department of Mines, Western Australia, 1896; from the Government of Western Australia.

United States Geological Survey, Sixteenth Annual Report, Part I, 1894–95; Seventeenth Annual Report, Part III (two vols.), 1895–96; from the U. S. Geological Survey.

The following from the Ordnance Office, U. S. America:—Annual Report of the United States Chief of Ordnance, 1896; Tests of Metals &c. at Watertown Arsenal, Massachusetts, 1893 and 1895; Notes on the Construction of Ordnance.

Untersuchungen an Schmidtschen Heiss-dampf-maschinen-anlagen, by M. F. Gutermuth; from the author.

Der Dampf-maschinen-bau und seine Beziehungen zur Elektrotechnik, by M. F. Gutermuth; from the author.

River Pollution, by Henry Robinson; from the author.

Leyton Electric Lighting, by Henry Robinson; from the author.

Report on Gas-Producing Plant and Gas-Engines, by Henry Robinson; from the author.

Metallurgy of Gold, with Notes, by Capt. C. C. Longridge; from the author.

Bertrand-Thiel Process of making Steel, by Percy C. Gilchrist; from the author.

Rede zum Geburtsfeste seiner Majestät des Kaisers und Königs Wilhelm II in der Aula der Königlichen Technischen Hochschule zu Berlin, 26 Januar 1897; from the Rector.

Souvenir of the Lighting of Niagara Furnace, North Tonawanda, U. S. A.; from Mr. Julius E. Waterous.

Alternating-Current Range and Position Finder, by Drs. Crehore and Squier; from the authors.

The Synchronograph, by Drs. Crehore and Squier; from the authors.

Register of the Institute of Chemistry of Great Britain and Ireland, 1897–98; from the Institute.

Report of the Kew Observatory Committee, 1896; Description of the Kew Observatory; from the Committee.

Electric Power Transmission in Works, by Daniel Adamson; from the author.

Report of Work of the Agricultural Experiment Stations of the University of California, 1894–95; Report of Work of the Agricultural Experiment Stations on Viticulture, 1887–95; Biennial Report of the President, 1894–96; Register, 1895–96; Bulletins, Vol. 1, Nos. 12, 13, 14; Vol. 2, Nos. 1, 2, 3; and various pamphlets; from the University.

Mechanical Refrigeration, by J. W. Anderson; from the author.

Electro-Deposition of Zinc, by Sherard Cowper-Coles; from the author.

Creation and Development of the Steam Engine, by H. W. Pearson; from the author.

Notes upon Gold Mining in Burma, by A. H. Bromly; from the author.

Note sur la Voiture de 1re. classe, série A N°. 199, figurant à l'Exposition Internationale de Bruxelles, 1897; from Mons. L. Salomon.

Essais comparatifs de Traction, by L. Salomon; Note complémentaire sur des Essais de Traction, by L. Salomon; from the author.

The following official publications from the Government of New South Wales:—Annual Report of the Railway Commissioners for the year ending 30 June 1897; Twelfth General Report of Committee on Public Works, 1897; Report of the Department of Public Works from 1 January 1894 to 30 June 1895; Annual Report of the Department of Mines and Agriculture, 1896; Wealth and Progress of New South Wales, Vol. 1, 1895–6, by T. A. Coghlan; the Seven Colonies of Australasia, 1895–6, by T. A. Coghlan.

Diesel's Rationeller Wärme-motor, by R. Diesel and M. Schröter; from Professor Schröter.

New Theory of the Stability of Ships, by Alfred J. Cooper; from the publisher.

Report *re* Cement Admixtures, with Evidence of Experts; from the London Chamber of Commerce.

Investigation of the Physical Properties of Compressed Iron Tyres, by Frederick Grover; from the author.

Annual Report of the Chief of the U. S. Bureau of Steam Engineering, 1897; from the Bureau.

Le Mécanisme du Lit Fluvial, by V. Lokhtine; from Mr. Leslie S. Robinson.

List of Chinese Lighthouses, Light-Vessels, Buoys, and Beacons, 1897; from the Inspector General of Chinese Customs.

Report on the Forests of Western Australia, by J. Ednie-Brown; from the author.

Report of the Hydraulic Engineer on the Water Supply of Queensland, 1896; from Mr. J. B. Henderson.

Presidential Address to the Institution of Mining and Metallurgy, 1897, by James Mactear; from the author.

Clarkson-Stanfield Dry-Ore Reduction Process; from the Clarkson-Stanfield Co.

The following by Mr. Jeremiah Head, from the author:—Manganese Ore Deposits; American and English methods of Manufacturing Steel Plates; Coal-Industry of the South-Eastern States of North-America; Charging Open-Hearth Furnaces by Machinery.

British Iron Trade Association, Report of Annual Meeting and Conference, May 1896; from Mr. Jeremiah Head.

The following from the India Office:—Papers regarding legislation for the Regulation and Sanitation of Mines in India; Revenue Despatches to India and Madras, Nos. 75 and 10; Report of the Inspection of Mines in India for the year ending 30th June 1896.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 31 Dec. 1896 and 30 June 1897; from the Registrar.

Photographs (two) of Non-compound six-wheel-coupled Goods Engines built at the Imperial Government Railway Works, Kobe, Japan; from Mr. R. F. Trevithick.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

The following from Sir Edward H. Carbutt, Bart.:—Royal Naval Exhibition, 1891, Official Report; Ship Railways, by W. Smith; Mine Rents and Mineral Royalties, by C. M. Percy; Main Drainage of London, Joint Report to London County Council; Constitution of our Harbour Trusts, by A. C. Schönberg; Guide to the Royal Arsenal, Woolwich, by W. T. Vincent; Expediency of Protection for Inventions, by F. J. Bramwell; History of the Steam Hammer, by T. S. Rowlandson; High-Pressure Steam generally, and its application to Quadruple Engines, by Daniel Adamson; Public Education of Austria, by J. Russell Endean. Reports to National Association for the Promotion of Technical and Secondary Education:—Technical Education in England and Wales, 1889; Second Annual Report, July 1889; Third Annual Report, 1889–90; Report on Scotch Education, 1889; Industrial Value of Technical Training, 1889; Catalogue of Books &c., 1889; Technical Education in a Scotch Town; Suggestions to County Councils; Night Schools and Technical Education, by S. Smith; Technical Education, by S. Smith. Manufacture of Textile Fabrics, by S. Smith; La Tour Eiffel, by G. Tissandier; Eight Hours' Day in British Engineering Industries, by J. S. Jeans; Light Railways, by Claude Vincent; Control of Indian Railways, by "V."; Railway Goods Tariffs of Germany, Belgium, and Holland, by Sir B. Samuelson, Bart.; Development of the Railway System of the Valley of the Ganges, by R. W. Crawford; Railway Administration (English) 1886; Report to Midland Railway on Continuous Brakes, by Messrs. Bramwell and Cowper; Proposed further Outlay upon the Navy, by Sir Edward J. Reed; State of the Navy, 1886, by H. F. Watt. U. S. Sub-Committee on Ordnance and Warships, Report on Visit to England; Great Gun Question, by R. A. E. Scott; Employment of Machine Guns with Infantry and Cavalry, by "P. N."; Cause of Rupture of Jacket, 6-inch breech-loading Wire Gun, by J. A. Longridge; Naval Guns and their Supply, by J. A. Longridge; Why did the "Thunderer's" Gun Burst? by J. A. Longridge; "Is England to be caught napping?" by J. A. Longridge; Our Big Guns, by Sir Frederick Bramwell; New Gun, by Capt. Callenberg; Quick's Breech-loading Ordnance; Our National Armament, by L. Thomas; Recent Gunnery, by Major G. Mackinlay. Bradford Corporation Water Works, Report by A. R. Binnie on Prevention of Waste of Water; Borough of Leeds, Report of Parliamentary Committee to the Leeds Town Council, 1877; Borough of Leeds, Reports on Electric Lighting 1882 and 1883; Position and Prospects of the Civil Engineers in the Indian Public Works Department; Note on the Nagpur and Chhattisgarh State Railway, by G. W. MacGeorge; Royal Arsenal, Woolwich, general plan, 1886; Royal Small-Arms Factory, Enfield Lock, index; Royal Powder Factory, Waltham Abbey, general plan; Naval Review, 1885, by Sir N. Barnaby; Mechanical Refrigeration, De la Vergne system; Easton, Anderson & Goolden, general catalogue; Thwaites Brothers, general catalogue; New Gülcher Electric-Light and Power Co., general catalogue; Technical Instruction, First Report (1 Vol.) and Second Report (4 Vols.) of the Royal Commissioners; Examination of Waters, Second Report by Dr. R. A. Smith; Light Railways, Report of Conference, 1894; Digest of Opinion of Parliament on the Powers and Management of Railways and Canals, by James Graham; Board of Trade memoranda on Registry and Inspection of Land Boilers. Parliamentary Reports on various subjects as under:—Telephone and Telegraph Wires; System under which Patterns of Warlike Stores are adopted and the Stores obtained and passed for H. M. Service; Organization and Administration of the Manufacturing Departments of the Army; Construction of Ordnance; Accidents in Mines, final report; Westminster Hall Restoration; Report on the "Daphne" Disaster, by Sir Edward J. Reed; Indian Railways, various reports, maps, memoranda, statistics, statements, and returns incidental thereto.

The following Abridgments of Specifications of Patents for Inventions, 1884–88:—Classes 10, 12, 18, 20, 34, 38, 44, 51, 52, 60, 61, 64, 66, 68, 69, 75, 78, 80, 81, 83, 85, 87, 89, 93–95, 102, 106–8, 110, 118, 123, 125, 126, 128, 130, 133, 135, 137, 138, 140.

Also the following in the Unillustrated Class 1877–83:—

Bleaching, Dyeing, and Printing Calico, and other Fabrics and Yarns.

Brewing, Wine-making, and Distilling Alcoholic Liquids.

Fire-arms and other Weapons, Ammunition and Accoutrements:—Div. I., Fire-arms and similar Weapons; Div. II., Cartridges, Projectiles and Explosives.

Photography.

Preparing and Cutting Cork, Bottling Liquids, Securing and Opening Bottles, and the like.

Sewing and Embroidering.

Wearing Apparel:—Div. I., Head Coverings; Div. II., Body Coverings; Div. III., Foot Coverings; Div. IV., Dress Fastenings and Jewellery.

Bibliographical Decimal Classification as applied to Railway Science, by L. Weissenbruch; from the Railway Congress Committee.

Water Lifts, by A. Chatterton; Experiments with Water Lifts, by A. Chatterton; from the author.

Report to the Governors of the City and Guilds of London Institute, March 1897; from the Institute.

City and Guilds of London Institute, Programmes of Central and Finsbury Technical College, 1897; from the Institute.

Calendars 1897–98 from the following Colleges:—Royal Technical High School, Berlin; Mason University College, Birmingham; Massachusetts Institute of Technology, Boston, U.S.A.; University College, Bristol; Glasgow and West of Scotland Technical College; Yorkshire College, Leeds; City of London College; King's College, London; Royal Technical High School, Munich (Calendar and Report); Civil Engineering College, Sibpur.

University of Wales, Calendar 1896–97; from the University.

Glasgow District Subway, its construction, plant and working, by A. H. Morton; from the author.

Aluminium, by A. G. Brown; from the author.

Appleby's Handbook of Machinery, Sections I., II., IV., and VI.; from the author.

Lockwood's Builder's and Contractor's Price Book, 1897; from the publishers.

Album of Views of Messrs. Thomas Firth and Sons' Norfolk Works, Sheffield; from Mr. J. E. Darbishire.

The Engineer's Compendium, 1897; from the publishers.

Illustrated Catalogue of Rails, Fish-plate and Sleeper Sections; from the Ebbw Vale Steel, Iron and Coal Co.

Expanded Metal and its uses in Fire-proof Constructions; from the Expanded Metal Co.

Illustrated Catalogue of Steel and Iron Wire-Ropes; from Messrs. George Cradock and Co.

General Catalogue of Worthington Pumping Machinery, 1897; from the Worthington Pumping Engine Co.

Illustrated Catalogue of Mathematical Instruments; from Mr. W. F. Stanley.

Universal Directory of Railway Officials, 1897; from Mr. S. Richardson Blundstone.

Donaldson's Engineers' Annual and Almanac, 1897; from Mr. Philip R. Owens.

General Catalogue of Worthington Pumps and Meters; from the Worthington Pumping Engine Co.

Illustrated Catalogue of Mining Machinery; from Messrs. Bowes, Scott, and Western.

"The Indian and Eastern Engineer" Diary, 1898; from the editor.

Whittaker's Mechanical Engineer's Pocket-book, by P. R. Björling; from the publishers.

Gas Engineer's Pocket Almanack, 1898; from Messrs. W. Sugg and Co.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.
Engravings from the École des Ponts et Chaussées, Paris.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Reports of the French Association for the Advancement of Science, 1894 and 1895.
Annales des Mines.
Annales du Conservatoire des Arts et Métiers.
Journal of the Marseilles Scientific and Industrial Society.
Proceedings of the Industrial Society of the North of France.
Proceedings of the Industrial Society of Rouen.
Proceedings of the Industrial Society of Mulhouse.
Bulletins of the French Technical Maritime Association.
Annals of the Association of Engineers of Ghent.
Proceedings of the Society of German Engineers.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Bulletins of the International Railway Congress.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Technical Society.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.

Transactions and Proceedings of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Journal of the Western Society of Engineers, Chicago.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Reports of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Journal of the Association of Engineering Societies.
Journal of the United States Artillery.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Engineering Association of New South Wales.
Journal and Proceedings of the Royal Society of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Institution of Electrical Engineers.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Proceedings of the South Staffordshire Institute of Iron and Steel Works' Managers.
Philosophical Transactions and Proceedings of the Royal Society of London.
Proceedings of the Royal Institution of Great Britain.
Transactions and Professional Notes of the Surveyors' Institution.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Journal of the Royal Agricultural Society of England.
Report of the British Association for the Advancement of Science.
Transactions of the British Association of Waterworks Engineers.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Journal of the Royal Institute of British Architects.

Transactions of the Incorporated Gas Institute.

Proceedings and Foreign Abstracts of the Physical Society of London.

Proceedings of the Literary and Philosophical Society of Manchester.

Transactions of the Manchester Geological Society.

Journal of the Royal Scottish Society of Arts.

Proceedings of the Philosophical Society of Glasgow.

Transactions of the Institution of Civil Engineers of Ireland.

Transactions and Proceedings of the Royal Irish Academy.

Transactions of the Institute of Marine Engineers.

Journal of the Society of Chemical Industry.

Transactions of the Manchester Association of Engineers.

Transactions of the Institution of Junior Engineers.

Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.

Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.

Forty-fourth Annual Report of the Liverpool Free Public Library.

Fourteenth Annual Report of the Barrow-in-Furness Free Public Library.

First and Second Annual Reports 1895 and 1896 of the John Crerar Library, Chicago; from the Library.

Catalogue of Additions during 1896 to the Radcliffe Library, Oxford.

Supplement to 1879 Catalogue of Books in the General Library and South Library of University College, London; from the College.

Library Catalogue, Horwich Mechanics' Institute, 2nd edition, 1896; from the Institute.

Catalogue of the Michigan Mining School, 1894–96; from the School.

The following Periodicals from the respective Editors :—

Arms and Explosives.
The Builder.
Camera Club Journal.
Cassier's Magazine.
Der Civil-Ingenieur.
The Colliery Guardian.
The Contract Journal.
Daily Tenders and Contracts.
The Electrical Engineer.
The Electrical Review.
The Engineer.
Engineering.
The Engineering and Mining Journal.
The Fireman.
The Journal of Gas Lighting.
Giornale del Genio Civile.
Glaser's Annalen.
Golfing and Cycling Illustrated.
The Indian and Eastern Engineer.
L'Industrie.
Industries and Iron.
El Ingeniero Español.

Invention.
The Iron and Coal Trades Review.
Iron Trade Circular, Ryland's.
The Ironmonger.
Ironmongery.
Lightning.
London Technical Education Gazette.
The Machinery Market.
The Marine Engineer.
The Mariner.
The Mechanical World.
The Mining Journal.
Phillips' Monthly Machinery Register.
The Plumber and Decorator.
The Practical Engineer.
The Printer's Engineer.
The Public Health Engineer.
The Railway Engineer.
Railway Master Mechanic.
The Railway Review.
Revue générale des Chemins de fer.
Revue industrielle.
Revue universelle des Mines.
The Shipping World.
Stahl und Eisen.
The Steamship.
The Textile Recorder.
Transport.

The President said that, in acknowledgment of the congratulations addressed to him by the Council, the following letter had been received from the Right Honourable W. J. Pirrie, who as Lord Mayor of Belfast had welcomed the Institution at the Summer Meeting in that city in 1896:—

Queen's Island, Belfast, 23 December 1897.

Dear Mr. Richards,

I am in receipt of your very nice letter of the 21st inst. regarding my appointment as a Privy Councillor; and have to thank you and the Council of the Institution for your kind expressions and congratulations, which are most gratifying to me.

With the compliments of the season,
I remain, yours very truly,
W. J. Pirrie.

E. Windsor Richards, Esq.,
President of the
Institution of Mechanical Engineers.

(The President.)

Of the step taken by the Council in enrolling the name of Professor Roberts-Austen as an Honorary Life Member of the Institution the Members had already signified their cordial approval during the reading of the announcement in the Report; and they would be glad to hear the following letter of acknowledgment which had been received from him:—

Royal Mint, 10 January 1898.

Dear Mr. Windsor Richards,

I have received with great pleasure your letter informing me that the Council of the Institution of Mechanical Engineers have done me the honour to enrol me as an Honorary Member of the Institution. I greatly appreciate this recognition of the value of work which the Institution has enabled me to conduct, and the graceful words with which you and the Council accompanied the bestowal of the honour.

I am, faithfully yours,
W. C. ROBERTS-AUSTEN.

E. Windsor Richards, Esq.,
President of the
Institution of Mechanical Engineers.

The Members he was sure would be pleased to hear a few words which the Auditor had added to his certificate respecting the Institution accounts. Mr. McLean wrote:—"The books and accounts have been invariably kept in the best manner which I could have wished, and the audit has therefore been to me a pleasure, as well as a matter of business."

On the Institution House it was seen from the Balance Sheet that the sum of £30,436 had already been expended. The details of this expenditure were as follows:—land, purchase of small freehold portion and premium on lease of rest, £10,474; ground rent £2,123; substructure £4,864; superstructure £11,100; ancient lights £240; fees and salaries £1,481; law charges £154. The land he was told could not be obtained now for less than £20,000. There had still to be spent upon the superstructure between £16,000 and £17,000.

If any Members wished to discuss any of the points dealt with in the Report of the Council, he should be happy to hear their remarks, and to answer any questions which might be asked thereon.

As no one seemed to have any remark to make, he would now move the adoption of the Report with the statement of accounts.

The motion was unanimously agreed to.

The President announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected :—

PRESIDENT.

Samuel W. Johnson,	Derby.

VICE-PRESIDENTS.

Arthur Keen,	Birmingham.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
William Dean,	Swindon.
Bryan Donkin,	London.
H. Graham Harris,	London.
T. Hurry Riches,	Cardiff.

For supplying the vacancy amongst the Members of Counicl. consequent upon the death of Mr. James Platt, the Council had appointed Mr. Edward B. Ellington as a Member of Council for the present year, his name being the next highest in the voting for the election at this Meeting. Agreeably with the articles of association, he would retire at the next Annual General Meeting, and would be eligible for re-election.

The Council for the present year will therefore be as follows:—

PRESIDENT.

Samuel W. Johnson,	Derby.

PAST-PRESIDENTS.

Sir William Anderson, K.C.B., D.C.L., F.R.S.,	Woolwich.
The Rt. Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S.,	Newcastle-on-Tyne.
Sir Lowthian Bell, Bart., F.R.S.,	Northallerton.
Sir Frederick J. Bramwell, Bart., D.C.L., LL.D., F.R.S.,	London.
Sir Edward H. Carbutt, Bart.,	London.
Charles Cochrane,	Stourbridge.
Jeremiah Head,	London.
Alexander B. W. Kennedy, LL.D., F.R.S.,	London.
E. Windsor Richards,	Low Moor.
John Robinson,	Leek.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Sir Douglas Galton, K.C.B., D.C.L., LL.D., F.R.S.,	London.
Arthur Keen,	Birmingham.
Edward P. Martin,	Dowlais.
William H. Maw,	London.
Sir William H. White, K.C.B., LL.D., D.Sc., F.R.S.,	London.
J. Hartley Wicksteed,	Leeds.

MEMBERS OF COUNCIL.

John A. F. Aspinall,	Horwich.
Henry Davey,	London.
William Dean,	Swindon.
Sir Benjamin A. Dobson,	Bolton.
Bryan Donkin,	London.
Edward B. Ellington,	London.
H. Graham Harris,	London.

Dr. John Hopkinson, F.R.S.,	London.
William Laird,	Birkenhead.
John G. Mair-Rumley,	London.
Henry D. Marshall,	Gainsborough.
Thomas Mudd,	West Hartlepool.
T. Hurry Riches,	Cardiff.
John I. Thornycroft, F.R.S.,	London.
A. Tannett Walker,	Leeds.

Mr. E. Windsor Richards said the time had now arrived when he must vacate the position he had occupied during the last two years as President of the Institution of Mechanical Engineers. To himself the post had been rendered most pleasant by the hearty co-operation of all his colleagues on the Council, and by the support at all times accorded to him by every member of the Institution. His successor he was sure would be as loyally supported, and therefore his term of office would be rendered as agreeable to him as his own had been. He had now great pleasure in asking Mr. Johnson to enter upon the occupancy of the chair.

Mr. Samuel W. Johnson, on taking the chair as President, offered his best thanks for the great honour which had been done him in his election as President of the Institution. Although his time was somewhat fully occupied, owing to other duties, he would do the best he could to promote the interests of the Institution while in office.

Sir Frederick Bramwell, Bart., Past-President, was sure the President would be desirous that the first of his acts in the chair should be to grant permission for the moving of a vote of thanks to the retiring President, Mr. Windsor Richards. As the senior Past-President present this evening, he claimed the privilege of being allowed to make this motion. Mr. Windsor Richards had been a Member of the Institution for a period of about one-third of a century—a large piece out of a man's life, and a larger piece still out of the life of an Institution only just half a century old. For half of this period Mr. Richards had been a member of the Council, first as an ordinary member of Council, then for six years as a Vice-President, and for the last two years as President. During these last two years he had had arduous work, largely due to the condition of the new building; because, although the new building had been initiated before he came into the presidency, the details of construction being numerous had largely occupied the attention of the Council during his term of office. In spite of his many engagements and of the fact that he was not resident in London, he had contrived somehow, as busy men did, to find time to attend practically the whole of the council meetings, a large number of committee meetings, and, as the Members knew, he had never failed in attending the General Meetings of the Institution during his presidency. That was not a bad record of work done for the Institution, and it was one for which they ought to be grateful. The members of the Council knew what the work had been; and the Members generally knew what their President's conduct had been in the chair; and he was sure they would recognise that, for tact in conducting their meetings, for sustained interest in the various papers brought before them, and for unremitting courtesy and kindness, no one could have exceeded their retiring President in performing the duties of the chair. He had therefore great pleasure in moving that the best thanks of the Institution be given to Mr. E. Windsor Richards for his conduct in the chair as President during the last two years.

Mr. Jeremiah Head, Past-President, was happy that, as next in seniority to Sir Frederick Bramwell of the Past-Presidents present, he could claim the privilege of seconding the motion just made. As to Mr. Windsor Richards' assiduous attention to his duties, and his ability in fulfilling the important and responsible office of President of the Institution for the last two years, he heartily endorsed everything which Sir Frederick Bramwell had said, as he was confident did all the Members. Mention might also be made of the circumstance, not always characteristic of even thoroughly good mechanical engineers, that Mr. Windsor Richards was one of those who to his mechanical knowledge, experience, and ability, added an admirable power of saying what had to be said in a concise, clear, forcible and elegant way. The Members would not respond any the less warmly to the motion when he reminded them that during his recent visit to America Mr. Richards had suffered a domestic bereavement in the death last month of his second son; and the Council at their meeting today had expressed their sympathy, which he was sure was shared by all the Members. He desired to second most heartily the resolution proposed by Sir Frederick Bramwell.

The motion was unanimously agreed to.

Mr. E. Windsor Richards heartily thanked the proposer, the seconder and the Members, for the kind way in which the vote of thanks to himself had been proposed and adopted. It was only carrying out to the end the support which they had given him from the beginning of his presidency; and he assured them he was most grateful for it.

The President reminded the Members that at the present meeting the appointment had to be made of an Auditor for the current year.

Mr. David Joy moved :—"That Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year at the same remuneration as last year, namely Twenty-five Guineas." Sir Frederick Bramwell and Mr. Head had both spoken of it as a privilege to move a resolution before the Institution. He personally felt it also an honour to move the present resolution; and it was likewise a great pleasure to him to do so, because in a way it identified him with the Institution, to which he had belonged for so many years, and with which he valued his connection so highly.

Mr. Thomas Instone seconded the motion, which was agreed to unanimously.

The Discussion upon Mr. Philip Dawson's Paper on "Mechanical features of Electric Traction," which had been adjourned from the preceding Autumn Meeting, was resumed and concluded.

At a Quarter to Ten o'clock the Meeting was adjourned to the following evening. The attendance was 136 Members and 113 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 11th February 1898, at Half-past Seven o'clock p.m.; SAMUEL W. JOHNSON, Esq., President, in the chair.

The PRESIDENT called upon Sir Douglas Galton to propose a vote of thanks to Mr. Bache on his retirement from the secretaryship of the Institution.

SIR DOUGLAS GALTON, Vice-President, said it was with mixed feelings that he heard himself called upon to propose a vote of thanks to Mr. Bache on his retirement from the position of Secretary to the Institution. He had himself had the honour of joining the Institution in 1862; but Mr. Bache had been a servant of the Institution ever since 1854, which was forty-four years ago. Mr. Bache had rendered most admirable service to the Institution; he had learned the ways of the Institution in its early years; he was with it when it was in Birmingham; and he subsequently followed its fortunes to London, where the Members all hoped it was now at last going to take its proper position in its own house, and to make practically a new start. Unfortunately for himself Mr. Bache had worked so hard for the interests of the Institution that he had injured his health materially eighteen months ago, and had consequently had to relax his exertions to some extent. He was happy to see that by that relaxation Mr. Bache was already restored to a considerable degree of capacity for still continuing to be useful to the Institution. Mr. Bache had expressed his willingness and his hope to be allowed after his retirement to assist the Council in any way in which it might be found desirable; and considering the large amount of extra work which must necessarily fall upon the Council during the present year in the arrangements for completing and entering into their new residence, they must all congratulate themselves that Mr. Bache would be at hand, and would be able to assist their admirable and excellent new Secretary in the consummation of this important step. All the Members of the Institution were fully aware of Mr. Bache's merits; and he did not think that he could add anything to their appreciation by repeating encomiums which were present to all their minds. He would therefore beg them to give a most hearty vote of thanks to Mr. Bache for the admirable way in which during forty-three years he had served the Institution, and especially for the admirable work which he had given to it during the last fourteen years prior to his retirement, while he had occupied the position of Secretary. He thought he ought to add that Mr. Bache had been appointed to the position of Secretary at a difficult time. There were occasionally difficult personal questions which arose in Institutions of this kind; and Mr. Bache became Secretary at a time when there had been an unusually difficult phase in the considerations which governed the practical management of the Institution work. Mr. Bache had displayed immense tact, immense geniality, and excellent methods of dealing both with the Council and with the Members; and he thought they ought to congratulate themselves that they had been so fortunate as to discover in Mr. Bache so excellent a Secretary. In moving the vote of thanks to Mr. Bache for his past services, he could not but regret that it was the practical breaking off of a connection which had been so advantageous to the Institution for so many years.

Mr. JEREMIAH HEAD, Past-President, having been asked at rather short notice to accept the privilege of seconding this vote of thanks to their retiring Secretary, might have pleaded want of longer notice as an excuse for saying little; but Mr. Bache's praises formed a subject that did not require much notice for anyone who had had as much experience of him as he had had. Sir Douglas Galton had reminded the Members of some of his qualities, and of the advantages which the Institution had enjoyed during a great number of years from having him as assistant secretary and as Secretary. Among other things he had referred to a somewhat critical state of affairs which occurred in the Institution about thirteen years ago, when Mr. Bache had not long been appointed Secretary. It had fallen to himself to have succeeded to the Presidency just at that period; and in conjunction with Mr. Bache he had had to contend with those difficulties. At the time he could assure the Members they were such that he had thought more than once of summarily resigning his Presidency as unbearable; but he had not done so, and had enjoyed the satisfaction in a comparatively short time of seeing the Institution emerge from those difficulties without being any the worse. In fulfilling the duties of President he must say that he had placed the greatest reliance upon the support, the energy, the activity, and the tact of Mr. Bache, who in fact had been indefatigable throughout that difficult and trying period. In that way they had managed by patience and perseverance to surmount all those difficulties; and now, as all knew, the Institution had achieved a state of prosperity, a state of usefulness, and a state of confidence in the future, such as it had never known before. He was exceedingly sorry that Mr. Bache had found it necessary to retire on account of his health; but he had not the slightest doubt, knowing his character, his indefatigable activity, and his tendency to exert himself beyond his strength, that he was doing the right thing at the right time. Although he trusted they were not going to lose sight of him for many and many a year, and although he was quite sure they would occasionally have to consult him, and that he would give them all the assistance in his power, he hoped that in his comparative retirement he would not now work more than was necessary for his own convenience and pleasure. The Institution was fortunate in having an excellent successor to him, who was perfectly worthy to fill the post occupied by Mr. Bache during the last fourteen years. He had great pleasure in seconding the resolution so appropriately proposed by Sir Douglas Galton; and he endorsed, as he was sure the Members would endorse, all the good and nice things the proposer had said of Mr. Bache.

Mr. Bernard Dawson said that on behalf of the rank and file, the great body of privates in the vast industrial army of Mechanical Engineers, he was very glad, as one of the middle-aged juniors of the Institution, to add his testimony to the value of what Mr. Bache had done for the Institution. Mr. Head had alluded to one of the greater crises which the Institution had passed through; and there had been also some minor occasions, sufficiently harassing, sufficiently annoying, and sufficiently worrying both to Mr. Bache and to the Council. They had survived a good deal of being damned with faint praise; and had been amused to hear that the solemnity of their proceedings was only equalled by the dismal mud-coloured garments in which the publications of the Institution were clothed; and other similarly complimentary criticisms had been indulged in. Whatever pain Mr. Bache might feel in severing himself from the Institution to which so many years of his life had been devoted, he thought he would yet be able to reflect that his work had been solid, substantial, and good, and that it had been characterised by integrity of purpose and by attention to the minor details as well as to the greater principles of the Institution. Any Members who like himself had had the pleasure of acting upon the local committees for Summer Meetings of the Institution would have a good idea of what the Secretary and his staff had to do towards maturing and carrying through the arrangements in the way in which the summer meetings of the Institution had invariably been managed. Besides last year's Jubilee meeting in Birmingham, and other summer meetings which might be regarded as near at home, to have taken the Institution, bag and baggage, to Paris and to other distant

(Mr. Bernard Dawson.)

cities, as Mr. Bache had done, reflected some credit upon the thoroughness and care which he had bestowed upon what, after all, were the important minor details that either made or marred the success of the summer meetings. He was glad to understand that Mr. Bache was not going to leave the Institution, nor to observe merely an attitude of benevolent neutrality; but that he would continue to do the best he could for their interests. If it should so happen that Mr. Worthington had to ask for advice from him, he was happy to know it would be given in the spirit in which it was asked. He believed that, when he took his hand from the plough, Mr. Bache could at any rate say that he had done something to consolidate the financial and technical position of the Institution, and in every other way had put them into such a position that, when they got into their new home, they might be able to hold their heads as high among the international and technical institutions of the world as they had every right to expect. Their excellent President, Past-Presidents and Council could be thoroughly relied upon for enabling them to do that. From what he knew, he considered that the Members could not have chosen a more worthy successor to the secretaryship; and he felt sure that it would be a satisfaction to Mr. Bache, in relinquishing the post, to know that he left the Institution in good hands, in which its interests would be conserved steadily, substantially and solidly, and it would be enabled to go on in that course of prosperity, which, when they entered their new building, he thought they might expect to be blessed with.

Mr. CHARLES HAWKSLEY, as one of the few members who had known Mr. Bache so long ago as when he was assistant secretary, desired to say that he heartily endorsed everything that had been expressed by the last speaker. He was sure that no one could have devoted himself with more heart and soul to the interests of the Institution than his old friend, Mr. Bache.

Mr. G. BLAKE OUGHTERSON, as an old member of over thirty years' standing, wished to express his great satisfaction at the courtesy which Mr. Bache had always shown to him and to all the other Members of the Institution during the period that he had occupied the position of assistant secretary and of Secretary to the Institution.

The resolution was unanimously adopted.

Mr. Alfred Bache was extremely obliged for the great cordiality with which the vote of thanks had been moved, seconded, supported, and carried; for the kind words of the several speakers; and for all the good and nice things, as Mr. Head had rightly characterised them, which had been said about his connection with the Institution. To himself it had been a very happy time during the whole of the forty-three years of that connection, and most particularly during the last fourteen years of his secretaryship. The work had been entirely congenial. If he had had his choice, he could not have chosen for life a work which he should have liked better, so thoroughly congenial had it proved. It had been rendered most delightful by the kind manner in which he had been treated by all the Members, by the great help that everyone had afforded, and by the friendly spirit in which everything he had attempted to do had been met. With regard to part of Mr. Head's kind remarks, he thought he ought in fairness to remind the Members that the circumstances were the other way round. It was certainly from Mr. Head's cool judgment, firm decision, and remarkable talent for viewing everything clearly and impartially from both sides and all round, that he had derived a strong confidence for meeting every matter that arose during the two eventful years when Mr. Head was President. It was a most fortunate thing for him that Mr. Head had been the President under whom he had then had to work. That had been a most happy time indeed; and he should like it to be fully understood that the success of so difficult a Presidency was really due to the clear, clever, and firm guidance exercised by Mr. Head. Fortunately under every succeeding President the same happy experience had been his. Now that he was leaving the work, he was bound to say that, although one who had so greatly enjoyed his work always regretted leaving it, yet he could not leave it under

(Mr. Alfred Bache.)

more propitious circumstances. Although it was only quite recently that he had had the pleasure of making the personal acquaintance of Mr. Worthington, he had in other ways known his family for many years; and it had been a great satisfaction to himself when things had so shaped themselves that the Council had decided upon recommending Mr. Worthington for appointment by the Members as his successor. The Institution he was quite sure would be in good hands, during what was now certainly another difficult time on account of the great amount of work that would devolve upon the new Secretary in connection with the new building. The work he was confident would be well done; and it would be a great gratification to himself to be permitted to render any help he possibly could for ensuring the successful housing of the Institution in the new building, in which it was going to make a fresh start on a further career of prosperity. He desired to thank the President and the Members most heartily.

The following Paper was read and partly discussed:—

"First Report to the Gas-Engine Research Committee: description of apparatus and methods, and preliminary results;" by Professor Frederic W. Burstall, of Birmingham.

The further Discussion upon this Paper, together with the remaining Paper announced for reading and discussion, was adjourned to the Spring Meeting of the Institution.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at a Quarter to Ten o'clock. The attendance was 94 Members and 80 Visitors.

(*Read* 4 *November* 1897.)

MECHANICAL FEATURES OF ELECTRIC TRACTION.

By Mr. PHILIP DAWSON, of London.

Introductory.—Previous to discussing certain special Mechanical Features which enter into the design and construction of an Electric Traction system, a few figures may be quoted for showing the importance of the subject in general.

Table 1 shows the mileage of tramways in America for the six years 1890–5. It is seen that rope traction continued to extend up to 1894; since that time its importance has diminished. In San Francisco, Los Angeles, Minneapolis, Denver, St. Louis, Pittsburg, Philadelphia, Baltimore, and other American cities, electric traction has been substituted in place of ropes.

Table 2 gives the electric tramway mileage in Europe at the end of 1896. It will be seen that Great Britain is yet much behind Germany. This is especially remarkable, because the regulations of German local authorities are generally much the more severe. Electric trolley roads are now to be found in the oldest and handsomest of German cities.

Table 3 shows the great financial importance of tramways as compared with railways in America. The passenger traffic on the tramways is six times greater than that on the railways; and the ratio of working expenses to receipts is lower for the tramways than for the railways. The gross earnings of the tramways in the United States are approximately 50 per cent. of the passenger earnings of the railways, and 15 per cent. of the total earnings of the railways, whereas the tramway mileage is only about 6 per cent. of the railway mileage. A highly important fact is that tramway receipts are found to be practically independent of good or bad trade, and not to depend on the prosperity of the country.

TABLE 1.—*Mileage of Tramways in America, and number of Cars, during six years* 1890–95.

	1890	1891	1892	1893	1894	1895
Mileage	Miles	Miles	Miles	Miles	Miles	Miles
Electric . .	2,523	4,061	5,939	7,466	9,008	12,583
Horse . . .	5,400	5,302	4,460	3,497	2,243	1,232
Rope . . .	510	594	646	657	662	599
Steam . . .	604	642	620	566	614	519
Total Miles . .	9,037	10,599	11,665	12,186	12,527	14,933
Number of Cars	Cars	Cars	Cars	Cars	Cars	Cars
Electric . .	5,592	8,892	13,415	18,233	24,849	36,121
Horse . . .	21,970	21,798	19,315	16,845	11,507	5,420
Rope . . .	3,795	4,372	3,971	4,805	4,673	4,871
Steam . . .	751	815	698	616	639	2,957
Total Cars . .	32,108	35,877	37,399	40,499	41,668	49,369

TABLE 2.—*Mileage of Electric Tramways in Europe, and number of Cars, and Horse-power, at end of* 1896.

Country.	Miles of Tramway.	Number of Cars.	Horse-power.
Germany	618	1,545	13,810
France	67	180	4,200
Great Britain and Colonies .	167	269	9,617
Austria and Hungary . .	120	265	5,060
Italy	50	149	2,460
Switzerland	30	83	1,570
Belgium	90	157	2,550
Russia	30	87	1,150
Other countries	30	50	111

TABLE 3.—*Comparison of Railways and Tramways in America and in England.*

Railways R	Tramways T	Capital Expenditure. £	Total Mileage.	Gross Receipts. G £	Total Expenses. E £	Ratio E to G Per cent.	Passengers carried
America	R	2,354,200,000	240,000	219,000,000	154,000,000	70	544,000,000
	T	280,000,000	14,000	32,850,000	22,700,000	68	3,000,000,000
United Kingdom	R	880,000,000	20,000	77,025,000	40,100,000	52	775,200,000
	T	13,000,000	1,000	3,540,000	2,640,000	75	480,000,000

TABLE 4.—*Cost of Tramways in small and large towns in Massachusetts.*

Per mile of single line.	Springfield.	West End.
Construction and equipment	£4,939	£11,323
Other permanent property	£1,761	£ 7,959
Total cost	£6,700	£19,282
Capital investment	£6,197	£20,152
Passengers carried, total	10,163,011	166,862,288
,, ,, per mile	180,547	648,568

TABLE 5.—*Passengers carried on Tramways and on Railways.*

		1895	1896
Worked by Horses only . . .	miles	61·799	35·132
,, ,, Electricity only . .	miles	1,002·756	1,241·363
,, ,, Horses and Electricity .	miles	22·62	14·54
Total Income	£	2,649,274	2,980,188
Dividend	per cent.	5·76	5·87
Passengers carried, total		259,794,308	292,358,942
,, ,, by Electricity . . .		205,866,134	236,544,417
,, ,, by Railway . . .		53,928,174	55,814,525
,, ,, excess by Electricity . .		151,937,960	180,729,892

TABLE 6.—*Growth of Massachusetts Tramways during ten years* 1887–96.

Year.	Number of Cos.	Miles of Main Line.	Miles equipped for Horses.	Miles equipped for Electricity.	Cost of Construction.	Cost of Equipment.	Capital investment.
1887	44	470·27	470·27	—	£3,524	£1,666	£6,534
1888	46	533·59	533·99	—	3,384	1,464	6,461
1889	46	574·17	523·65	50·52	3,236	1,576	6,781
1890	48	612·38	451·52	160·86	3,467	2,131	7,651
1891	56	672·45	383·42	289·03	3,584	2,323	8,178
1892	61	754·85	258·55	496·30	3,904	3,043	9,230
1893	60	874·14	163·06	711·08	5,358	2,347	10,673
1894	68	928·84	103·87	824·97	5,349	2,305	10,592
1895	75	1077·99	61·80	1016·19	4,797	2,096	9,820
1896	83	1276·75	35·13	1241·62	4,679	1,961	9,278

Year.	Passengers carried.	Car-Miles run.	Persons employed.	Cars.	Horses.	Motors.
1887	124,787,328	20,625,846	5 222	2,633	11,874	—
1888	134,478,319	23,241,767	5,531	2,588	11,391	—
1889	148,189,403	24,259,491	6,302	2,912	11,817	—
1890	164,873,846	26,516,937	6,246	3,247	11,241	—
1891	176,090,189	27,670,166	6,449	3,494	10,640	—
1892	194,171,942	29,678,036	7,185	3,679	6,734	—
1893	213,552,009	31,507,282	8,070	4,010	3,531	3,013
1894	220,464,099	36,722,978	7,451	4,058	2,014	3,906
1895	259,794,308	43,655,560	8,018	4,426	1,436	4,704
1896	292,358,943	53,613,685	9,130	4,913	878	5,958

Tables 4, 5, and 6 have been compiled from the official reports of the Massachusetts Board of Railroad Commissioners. Massachusetts more closely resembles England in the habits of the people and in local conditions than any other State of the Union. Table 6 shows the rapid increase of passenger traffic and mileage. Table 4 shows the difference in cost of completely equipping tramways in small and large towns, varying from £7,000 to £20,000 per mile of single line. Table 5 shows that as passenger carriers tramways play a much more important part than railways. It is demonstrated, not only in America but also in England and on the Continent, that wherever an electric tramway runs parallel to a railway the tramway will secure practically all local traffic. It has been frequently urged that mechanical motive power on tramways is dangerous to the public safety. In America, where comparatively high speeds are allowed, the Railroad Commissioners report that the proportion of passengers and employés killed during the last two years of electric working appears to have been about the same as with the use of horse-power in 1888.

For all practical purposes the present subject may be considered under the three headings of outside work, rolling stock, and power station.

Outside Work.—Wires.—The overhead line of conductors or trolley wires may be supported either by brackets attached to poles or to houses, or by a transverse span-wire stretched across the track between poles or rosettes fixed to house-fronts. For the sake both of appearances and of smooth running, the conducting or trolley wire should be strained as tight as is consistent with its tensile strength and with the minimum temperature which obtains in the locality. The best practice does not allow more than 2,000 lbs. strain on a No. 0 Brown and Sharpe (0·325 inch diameter) hard-drawn copper wire at the lowest temperature to which it will be exposed. With this limit the strain to be put on the wire when erected can be easily ascertained from tables. For fixing the maximum sag to be allowed for the cross or span-wire in spans ranging from 30 to 120 feet, the curves given in Fig. 1, Plate 1, are useful, showing the corresponding pull produced upon the poles by a seven-stranded steel span-wire, 5–16ths inch diameter, carrying in the centre of its sag a single conducting or trolley wire of copper, 0·325 inch diameter, having a span of 125 feet between successive cross or span-wires. For the longitudinal or conducting copper wire a rough but safe rule in this country, where rarely more than 20° Fahr. of frost is to be expected, is a sag of 0·75 per cent. of the span at an average temperature of from 60° to 65°. The conducting or trolley wire should be of absolutely even quality, and supplied in lengths of slightly over half a mile. The joints should be silver-brazed in the copper ingot before it is rolled. The diameter of the copper wire should not be allowed to vary more than 0·0004 inch; its breaking strain should be at the rate of 56,000 lbs. or 25 tons per square inch. For the cross or span-wire it is necessary to determine both the height of the eye-bolts from which it is suspended, and also the sag. In Table 7 are given data of galvanized steel span-wires generally used.

Poles.—Upon the amount of sag allowed for the span-wires depends the strain which the side poles must stand. Round curves these strains are often great, and tubular poles composed of ordinary pipes wedged together by liners are useless. In Table 8 are given certain data of standard poles specially designed for this work. All poles must be of such strength that when in position they will stand without permanent set the greatest side strains to which they may be subjected. Terminal poles and pull-off poles on curves should be the strongest. Ordinary side poles must stand a direct strain of at least 500 lbs. without deflecting more than 4 to 6 inches. Their strength must be sufficient to carry, besides the trolley wire itself, the additional weight when the wires are covered with ice and snow. The poles are always subject to vibration communicated from the trolley wire. It is of the utmost importance that joints should be well constructed: which renders it necessary that the several lengths of the pole should be sweated together as shown in Figs. 2 and 3, Plate 1. The joint is made by heating the outside pipe to a welding heat, slipping it over the inner pipe, and then passing the two together through

TABLE 7.—*Galvanized Steel Span-Wires.*

Thickness of Wire	wire-gauge No.	15	12	11	10
	inch	0·070	0·110	0·120	0·135
Number of strands		7	7	7	7
Total approximate diameter	inch	1-4th	5-16ths	3-8ths	7-16ths
Weight per hundred feet run	lbs.	10	21	29	36
Tensile strength absolute	lbs.	1,600	3,360	4,610	5,720

TABLE 8.—*Standard Tubular Poles.*

Total Length of Pole.	Length and outside Diameter of three component Pipes.			Total Weight.	Free from Permanent Set at
Feet.	Feet. Inches.	Feet. Inches.	Feet. Inches.	Lbs.	Lbs.
29	16½ × 10	8 × 8	7¼ × 7	1,503	4,500
30	17 × 10	8½ × 8	7¼ × 7	1,552	4,400
31	17 × 10	9½ × 8	7½ × 7	1,593	4,200
28½	16 × 8	8 × 7	7¼ × 6	1,193	3,400
29½	16 × 8	9 × 7	7¼ × 6	1,224	3,200
30	17 × 8	8½ × 7	7¼ × 6	1,259	3,150
28½	16 × 7	8 × 6	7¼ × 5	769	2,000
29½	16 × 7	9 × 6	7¼ × 5	991	2,000
30	17 × 7	8½ × 6	7¼ × 5	998	1,800
28½	16 × 6	8 × 5	7¼ × 4	689	1,200
29½	16 × 6	9 × 5	7¼ × 4	613	1,000

special rollers. After completion, if a piece is cut from the joint between A and B, the two pipes will be found solidly welded together, the joining line AB having entirely disappeared. This is known as the "S S S" joint, the abbreviation meaning solid, swaged, and sweated. The tubes used in making poles are all lap-welded, and the larger sizes are also riveted along the seam with countersunk rivets. The lengths of pipe are so put together that the seams of each consecutive length are 120° apart, Fig. 4, when the poles are made in three lengths, as is generally the case. If joints are not so made, the pole, instead of bending uniformly as shown in Fig. 5, after a short time gives at the joints, as shown in Fig. 6. Poles constructed with S S S joints can be accurately calculated to stand any determined strain without exceeding a fixed temporary and permanent deflection. This is not possible with other joints, which always give trouble sooner or later.

For the standard poles used at Bristol and Dublin five sizes are required, all 31 feet long, and set in the ground to a depth of 6 feet. No. 1 has to stand a lateral strain of 350 lbs. applied at top, with maximum temporary deflection of 6 inches; and a strain of 700 lbs. with maximum permanent deflection of ½ inch. For the four others the corresponding limits are:—

No. 1 . .	350 lbs.	with 6 inches,	and	700 lbs.	with ½ inch.
No. 2 . .	500 ,,	,, ,,	,,	1,000 ,,	,,
No. 3 . .	700 ,,	,, ,,	,,	1,200 ,,	,,
No. 4 . .	1,000 ,,	,, ,,	,,	1,700 ,,	,,
No. 5 . .	2,000 ,,	,, ,,	,,	2,600 ,,	,,

The poles are required to be as nearly round as possible. A difference of 1–8th inch between maximum and minimum diameter is all that is allowed. In order that they may all be as nearly uniform as possible, 1–16th inch more or less than the prescribed dimensions is all that is allowed. The greatest distance out of the true that is allowed at the top of the pole is 1–4th inch. Ten per cent. of each lot of poles are tested; should three poles fail to come up to the requirements, the right is reserved to reject the entire lot. The poles are dropped three times, butt foremost, from a height of 6 feet upon some solid substance; after which they must show no signs of telescoping or loosening in the joints.

Insulators.—Insulators must be mechanically strong, and the insulation protected by a metallic covering from external injury. Special insulators have been designed for every variety of service, samples of which are exhibited. For ordinary tramway service the wire is usually soldered into the gunmetal ears of the insulators; but the heavy "figure 8" wire, used for light railways and high-speed lines, is supported by mechanical clips. Occasionally an extra heavy round wire is used, 9–16ths inch diameter, which is then milled out by a portable tool at the points of support, in order to afford a proper grip for the mechanical ears, as shown in Fig. 7, Plate 1.

Rolling Stock.—This can be subdivided into car-bodies, trucks, motors, and their accessories. The bodies possess no special features, except that all framing must be extra strong.

Trucks.—The supply of suitable trucks for both motor and trailer cars is of the utmost importance. The introduction of electric traction has revolutionised the construction of running gear. In former days, when horses and mules were the only motive power for street cars, it was considered quite sufficient to support the car body upon a single set of springs carried by the axle-boxes, a simple bar being often the only connection between the two sets of wheels. The adoption of electric power, and of cars equipped with single or double motors, added immensely to the weight carried by the axles, and rendered it necessary to adopt efficient methods for cushioning and suspending the motors over the axles, while maintaining a rigid connection between motor and axle. At first the motors were rigidly attached to the bottom of the floor of the car body. This construction did not prove a success, for both car floor and motor deteriorated rapidly, and access to the motors was also difficult.

Experience demonstrated that the only effective plan was to attach the motors to an independent truck-frame, and to have all the mechanism of the car entirely independent of the car body. For this purpose an independent truck was introduced, consisting of pedestals secured by centre bars; upon the pedestals the motors were suspended by cross-bars connecting the side frames of the truck together. While these trucks supported the motors independently of the car body, they did not properly support the car body itself, which had increased in length and width. The increased length and width of the electric car, together with the increased speed at which it ran, rendered a stronger and longer truck necessary. At first the old street-car pedestals were fastened to a separate pair of sills. The axle-boxes still played up and down in these pedestals to the full extent of the motion of the car body. This device proved insufficient. The next step in advance was to secure the pedestals carrying the axle-boxes to side frames, which carried the springs supporting the car body. This construction however allowed excessive swaying of the car body, owing to the fact of the connection between the wheels and the body not being sufficiently rigid. Moreover no provision had been made for easily removing the wheels, which required the truck to be practically taken to pieces. The brakes were hung to the upper chord of the truck, the effect of which was that, when the springs were compressed, the brake shoes dropped lower on the wheels, changing the distance between the shoe and the wheel.

The introduction of mechanical motors, occupying so little room that a capacity of fifty or sixty horse-power can readily be placed in the space allowed by the truck, has led to a large increase in the weight of the car body, and a consequent lengthening of the wheel-base. The modern electric-car bodies carried on four wheels are seldom shorter than 18 feet over the end panels, and sometimes reach 22 feet length, exclusive of the platforms, while the whole length of the car over the platforms is from 30 to 32 feet. This increase of nearly 25 per cent. in the length and more than 25 per cent. in the weight of the bodies has been accompanied by an increase of only about 20 per cent. in the wheel-base of the trucks. As a result, a long and rigid spring-base is an absolute necessity for a modern electric truck. Without this, the whole stress of carrying both the dead weight of the car and platforms and the fluctuating weight of the load would fall on the car sills and body, and the motion of the car would continually wrench and strain its framing. In the conditions met with in street service the wheel-base cannot be lengthened much over 7 or 7½ feet; and on this account a long spring-base must serve the purpose of an increased wheel-base for the long cars now employed. To obtain easy riding it is necessary that all the springs should be sufficiently light to obviate vertical motion in the car body; consequently these light springs, in order to prevent excessive motion of the ends of the car, must be carried out just as far apart as it would be necessary to carry the wheels if the old horse-car arrangement were adopted for the modern long-car bodies.

To secure the necessary rigidity of the long side-frames, and at the same time keep their weight within reasonable limits, different plans have been adopted. In earlier designs it was attempted to overcome the difficulty by casting the pedestal and overhang in one piece, and lengthening the joint between these castings and the bars, connecting them as shown in Fig. 8, Plate 2, which represents one of the early forms of the extended spring-base. Another method consisted in trussing the overhang with straining rods running over the tops of the pedestals, Fig. 9, and provided with turn-buckles for taking up the strain as the overhang worked down; but turn-buckles slack off, and the bolted joints wear loose, and a continual wear and rattle was the result. Some makers constructed the side frames of the truck in one piece, by bolting heavy centre-bars to the pedestals. Others again forged the side frame of the truck, and welded the whole together into one piece. But these designs have not proved sufficiently strong to support properly the permanent pressure upon the ends of the overhang, when the overhang is carried out to the length of the modern car-body.

The demand for this special class of work brought out a host of devices, of which ten years' experience has sifted the useful from the useless; and it may be fairly stated that the chief principles involved in the design of a thoroughly good motor-truck, fulfilling all or most of the conditions imposed by electric traction, have now been fully recognized, with the result that the electric motor-truck has been matured to a standard form. Truck building has become an independent business in America, although many car works still make some form of truck for themselves. Rigid frames had been employed in trucks for cars driven by gas, steam, compressed air, or cable grip; but in all of these the conditions are entirely different from those in electric motor-cars. This experience was dearly bought by some of the earlier electric tramways, as was testified by many a scrap-heap composed of trucks which, after running but a few miles, had to be discarded.

The quality of the motor trucks may mean the success or failure of an electric tramway; and to secure a good truck is quite as indispensable as to use a well-constructed and efficient motor. A motor truck comprises many parts, the most important of which are the side frames, springs, wheels, axles, boxes, bearings, motor bearings and suspension, sand-boxes, brakes, and safety appliances. The following are the essential conditions which must be fulfilled by a truck in order that it may be suitable for electric traction:—

1. The truck must be as light as possible, consistently with rigidity and strength.

2. It must be thoroughly braced, so as to keep it stiff and square without having to depend in any way on the car body. The strains on a motor car in rounding curves, and when passing a change of gradient, are extremely severe: much more so than with horse-cars, where the horses pull the car round on curves, and go slower at a change of gradient.

3. The journal-boxes must be self-lubricating, must require but little attention, and must be dust-proof.

4. The brake action must be simple, effective, and easily adjustable; and the brake shoes must admit of being replaced at a moment's notice, and must be mounted in such a way as not to be influenced by the vertical motion of the car.

5. The truck must be constructed in such a manner as to render access easy to all parts; and to admit of motors, wheels and axles, journal-boxes, brake-gear, and other parts, being easily removed,

without having to dismember the truck. Cross strains on bolts should be avoided as much as possible.

6. The car body must be attached to the truck in such a manner as to be readily removed on loosening a few bolts.

7. Springs must be arranged so as to render the running of the car as smooth when empty as when fully loaded, and to prevent the pitching and rolling motion to which street cars are so liable on sharp curves and rough roads. This is a highly important point, not only for the comfort of the passengers, but also to prevent rapid deterioration of the car wiring and car bodies; deterioration of the wiring is likely to cause grave results to the motors by producing short circuits.

8. An appropriate choice of wheels is most important.

There are three different kinds of trucks: the rigid four-wheel, the radial six-wheel, and the four-wheel bogie for eight-wheel cars. Of these three however only the first and third are generally used, the radial truck not having given the satisfactcry results which were expected.

Four-wheel Truck.—In the rigid four-wheel truck, where the wheel-base is naturally restricted, it is of the greatest importance to have an arrangement whereby the car body is supported as far outside the wheel-base as possible; and to diminish as much as may be, by the judicious use of springs, the destructive effect of jolting, both upon the car body and upon the motor equipment. The best modern truck, which has been employed on all the latest and best-equipped British and colonial tramways, is the "Peckham," of which models are exhibited. It has been adopted by Bristol, Dublin, Guernsey, Clontarf, Coventry, Isle of Man, North Staffordshire, Dover, Leeds, Birmingham, Brisbane, Sydney, and other places; and in all cases has given the utmost satisfaction. The support selected as the model for a truck frame is the standard cantilever bridge-truss, which experience in bridge building has shown to be the strongest form of construction. This truss principle has been closely followed in the construction of the Peckham truck, Plates 4 and 5; and while various modifications in detail have been made to adapt trucks to the various conditions occurring in street tramway practice, the characteristic bridge form of truss has been strictly adhered to in all of them. The cantilever truck has now come to be regarded as the standard for the best work in the United States, inasmuch as 15,000 are now in use in that country.

As the length of the car body grows greater, the difficulty increases of supporting it properly at the ends, without increasing the height of the car platform above the ground. The resistance offered by any truss to bending varies directly as the cube of its depth. If therefore the car platform were raised high enough above the street level, it would be an easy matter to support the sills of any car effectually so that it should be impossible for them to droop at the ends under heavy loads. It is an entirely different thing however so to support them, when the height from the rail to the lower edge of the sill is limited, as it must be in street tramways. Beyond twenty-seven or at most thirty inches, every inch that the car platform is raised above the level of the street makes it so much the more difficult for ingress and egress. This is therefore practically the limit in height to which the car body used for city service can be raised. This problem has been solved by the use of extension rods, in a way never before applied in street tramways. A second bridge truss is constructed by employing the extension rod as a lower member and the car sill as an upper member; and this truss is supported flexibly upon the main truck truss. The truss extension-rods, instead of terminating as heretofore at the extremity of the truck frame, are carried below and around its lower member, and are stayed to the car sill by bolts passing through the truck pedestals and end springs. The angle of the truss extension-rods has not been changed in any way to secure a longer support; but as they are dropped bodily lower, they give a wider base of support to the car body than would otherwise be possible. By this method it has been found practicable to carry upon single trucks, with a wheel-base of only seven feet, cars as long as thirty-five feet, Plate 5.

Other important improvements include the flexible gear, which is so constructed that it allows the cantilever extension-truss to be built in sections: so that the portion under the journal boxes can be removed when necessary for taking out the wheels and axles, but when in place it makes a continuous truss. This gear also allows of introducing in its upper portion coil springs, for supporting the truck frames flexibly upon the journal boxes, thereby relieving the truck frames as well as the car body from the rigid metal contact with the rail, and also relieving the rail from the hammer-blow which would attend a rigid connection between the rail and the car body.

Swivel Truck.—The rapid growth of inter-urban lines, upon which the tendency is to use long cars—and the desire on many tramways to use long cars for city work—have resulted in the swivel truck, shown in Fig. 10, Plate 2. This is the result not only of railway experience, but also of many years' experience of electric tramway needs. A truck so constructed runs exceedingly easy, the weight being doubly cushioned by the two elliptical springs and spiral springs over each axle-box. The brake gear is simple, and the shoes are applied with a powerful leverage. The centre of gravity of the trucks has been brought down as low as possible; with cars having straight sides, the body of the car need not be more than 27½ inches above the rail. The wheel-base has been kept short, and the space between the axles kept clear, so that it is possible to mount two motors on the truck without difficulty. The arrangement of the springs on the trucks renders it possible to remove the bolster and elliptic springs quickly and easily, whenever it becomes necessary to examine and overhaul the motors. When this has to be done, the car body is simply jacked up with the bolster, and the truck frame can then be run out from under the car. The rivets used in the construction of all these trucks are driven in hot by means of pneumatic riveters under 30 tons pressure.

Peckham Trucks.—The accompanying Table 9 gives the general dimensions &c. of these trucks and of the cars they carry on electric tramways in England and Ireland. By these trucks cars of as great a length as 27 feet over all are carried on a wheel-base as short as 5½ feet with no longitudinal oscillation of any kind when running.

TABLE 9.—*Examples of Peckham Trucks in England and Ireland.*

Weight of Car body with roof seats, 2 tons.

Where running	Bristol.	Bristol Extension.	Dublin Southern.	Dublin Clontarf.	Leeds.	Plymouth.	Dover.	Cork.	Coventry.
	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins. and Ft. Ins.
Length of Wheel base .	5 6	5 6	6 0	6 0	6 0	5 6	5 6	6 0	6 6 and 5 6
" " Spring base .	11 8	13 2	12 8	12 8	13 8	11 8	11 8	13 9	14 0 and 11 8
" " Top Frame .	13 2	14 9½	14 0	14 0	15 3½	13 2	13 2	15 3½	16 0 and 13 3
Gauge of rails . . .	4 8½	4 8½	5 2$\frac{3}{16}$	5 2$\frac{3}{16}$	4 8½	3 6	3 6	3 0	3 6 and 3 6
Length of Car body over doors	13 2	16 8	16 8	16 8	16 0	14 0	15 0	14 8	19 2 and 14 1½
Length of Car body over dashboards . .	24 8	27 2	25 2	25 2	26 6	24 6	25 0	25 2	27 8½ and 22 7½
Capacity of Car, number of persons . .	43	53	53	53	50	41	44	44	54 and 40
Weight of Truck lbs.	4,690	4,448	4,658	4,522	4,690	4,690	4,690	4,450	5,112 and 4,782
Weight of Motor Car running empty, tons	8	8¾	8¾	8¾	8½	8¼	8	8	9 and 8
Diameter of Axles, inches	3¾	3¾	3¾	3¾	3¾	3¾	3¾	3¾	3⅜ and 3⅜
Weight of each Axle, lbs.	140	140	159	159	140	120	120	100	110 and 110
" " " Wheel, 30 inches diameter, lbs.	330	330	330	303	322	330	330	330	330 and 330

Class of Truck.—Bristol, Dublin Southern, Dublin Clontarf: standard cantilever extension 6 C. Bristol Extension; extra long 6 E Z. Cork: improved extra long 8 C. Coventry: extra long 6 E, and standard 6 C. Dover: standard cantilever extension. Leeds: extra strong No. 9. Plymouth: standard cantilever extension.

For ordinary local tramways, cars of the sizes and capacities here given are found to be well adapted for the purposes they serve. With the demand for inter-urban and railway service however, still longer cars have become necessary; and practice has shown that the best way to carry a long car is on two trucks, each having a short wheel-base. As a consequence it is also required that the car body should be mounted on some swivelling arrangement, otherwise owing to its length it would be severely racked in going round curves. On any particular route the sharpest curve is naturally a primary factor in determining the greatest length of wheel-base. The following are the maximum lengths of wheel-base advisable for curves of the mean radii given :—

Minimum mean radius of curve, feet . .	25	30	40	50	60
Maximum length of wheel-base, feet . .	6	6½	7	7½	8

It is possible to use a wheel-base of 6½ feet on a curve of 25 feet mean radius, or a wheel-base of 7 feet on a curve of 30 feet mean radius, without danger of running off the rails, provided the latter are laid exactly to gauge and are protected with guard rails. These swivelling or bogie trucks are found to require more current in proportion to the total weight carried than the ordinary single trucks, owing to their having eight wheels instead of four, with consequent greater wheel friction in addition to the friction of the two sets of swivelling plates.

With the double truck and bogie equipment the next question that comes up is the number and distribution of the motors. If the weight of the car is equally distributed on the four axles and there is a motor on each axle, that is to say four motors in all, then the starting torque or turning moment which can be exerted before skidding takes place is equal to the total adhesion of the truck. But if, on account of the total power required or for other reasons, only two motors are employed, then the relative distribution of the weight becomes of the highest importance; because, if the weight is equally distributed on all the four axles, only half the total adhesion of the truck is available for starting. The distribution must therefore be such that the greater part of the weight is carried by the axle to which the motor gears. Trucks of this kind, which are called maximum-traction trucks, have now been in use for some time in Guernsey, and are shortly to be running at Middlesbrough. Of the models exhibited, one represents a four-wheel single truck, of which one half is of the extra long kind and the other half is of the standard length; and the other model represents one of a pair of double bogie trucks with equal traction for each axle. In Plates 3 and 4 is shown one of a pair of maximum-traction trucks, on which the car body is supported nearer to the driving wheels than to the smaller wheels. By this arrangement it is possible for as much as 80 per cent. of the weight to be thrown upon the driving axles.

In all bogie trucks, whether of maximum or of equal traction, the car body must be free to swivel round its point of support with minimum friction. With this view the motion of rubbing surfaces relatively to each other must be as small as possible, and all dirt must be excluded from them. These objects are realised by means of swivelling plates, of which the recessed plate is carried on the top of a bolster and is situated midway between the two sides of the car sill, so that the relative motion of the two plates is small and the leverage of the friction is reduced to a minimum, because the diameter of the swivelling plates is only six inches. This plan is obviously much superior to any side rollers, with which not only is the relative motion much increased but also the moving surfaces are exposed to dirt.

As it is likely that these bogie trucks will in the near future be required for much higher speeds, they are most carefully cushioned, and every precaution is taken to make them run easily round curves. In the model shown, and in Figs. 11 to 13, Plates 3 and 4, it will be seen that the car is carried on a swing bolster, to which the recessed swivel-plate is bolted, Fig. 13; the bolster is supported from what is called a spring plank by three springs, two spiral springs at either side and a half elliptic spring in the middle; while the plank itself is hung by links from a pin, which in its turn is supported by a cushion pocket. Thus the bolster is thrice cushioned, namely by the springs on the axle-boxes, by the cushion pocket, and by the three springs under the bolster.

In the material used and in their general construction all these trucks are the same, Plates 3 to 5. The side frames are composed of soft-steel bars, secured to malleable-iron pedestals by hot rivets driven in by a pneumatic riveter at 30 tons pressure. The end portions are supported from underneath by trusses, attached to the extreme end portions of the side frames and to the base of the pedestal; and the truss bars are so secured in pockets that the rivets holding them in place are not subjected to shearing strains. The main side-bars are also secured in accurately fitted grooves in the sides of the pedestal arms, so that the downward strain comes directly upon the pedestals and not upon the rivets. The upper cross section of the pedestals is cylindrical in shape, and hollow, Fig. 14, Plate 4; and the pedestals are fitted with double-coil springs, resting upon the journal boxes and sustaining the entire weight of the truck frames, so as to relieve from all shocks both the truck frames and also the motors suspended therefrom. The openings at the bottom of the pedestals, for removing the journal boxes, are provided with removable keeps or braces, accurately machined to fit into the openings in the pedestals, and secured in place by removable bolts provided with split pins. When in place, these keeps make the cantilever truss continuous from end to end. The side frames are provided at top with a continuous bar, in which are recesses for receiving the spring bolts, so that these can be removed without jacking up the car body.

The springs for supporting the car body upon the truck consist of both elliptic and coil springs, Fig. 16, Plate 5, so combined and graduated that the weight of the car comes first upon the elliptic springs, and as the load increases the coil springs are brought into play. With this arrangement of springs the car rides easily, whether lightly or heavily loaded, and the springs themselves are not overloaded. In Fig. 16 the truck is supposed to be loaded with the empty car body, the dead weight of which is wholly supported by the elliptic springs, while the coil springs are shown ready to take their part in supporting the live load as soon as it comes on.

The brake blocks are provided with removable repair-pieces or liners, for taking up lost motion as they become worn, thus preventing noise. They are also furnished with positive pull-back coil-springs for releasing the brake shoes from the wheels. The brake shoes are separate from the heads or hangers in which they are fitted, Fig. 16, Plate 5; and are so constructed as to be interchangeable and easily removable without loosening the bolts.

Each truck is fitted at its outer end with an adjustable life and wheel guard, which can be adjusted easily to any desired height from the road. All trucks are fitted with best chilled-iron wheels, of which the flanges are shaped to suit the rails they will have to run on.

Motors.—In the early days the motors were all used with double-reduction gearing, with so great a consequent waste of power in a double transformation of the high armature-speed to the low speed of the car axles that an efficiency of 60 per cent. was rarely obtained. At present, good design, workmanship, and materials have brought about such a change for the better that under most conditions an efficiency of 80 per cent. is attained, which remains constant with widely varying loads. When the application of electricity for propelling street cars was first practically attempted, it was endeavoured to apply the existing stationary motor to the existing running gear. The motor and axle were connected by means of belts, sprocket chains, friction clutches, and other mechanical devices, all of which, with few exceptions, have now been abandoned, on account of the great expense of maintenance and their low efficiency. Double-reduction spur-gearing was first introduced on the experimental line at Woonsocket, Rhode Island, which was jointly equipped in 1886 by the Thomson-Houston and Bentley-Knight companies; and the advantages of a specially constructed and self-contained motor-truck were there demonstrated. The high speed and comparatively cumbersome construction of motors at that time necessitated a double reduction in gear between armature and axle, each reduction being about 9 to 1. Thus an armature speed of about 1,500 revolutions per minute gave a car speed of about 15 miles per hour. The later makes of double-reduction motors, of which a great many have been employed both in the United States and in Europe, have done excellent work; but more recent and keener competition in electric traction has resulted in more advanced designs being developed.

The electric motor having demonstrated its ability to do the required work, the next problem was so to improve it as to reduce the working expenses as low as possible. This was partially effected by improving the design of the double-reduction motor, and to a much greater extent by the introduction of single-reduction gearing. The success of single-reduction stimulated still further improvement in design; and motors mounted direct upon the driven axles, and devoid of all gearing, were developed. These however have not yet come into practical use for street cars, on account of their increased weight and also of their rapid deterioration owing to the absence of any spring support, in consequence of which the motors receive all the shocks due to the comparatively rough tramway lines. The increased weight and rapid deterioration, and consequent increase in original cost and maintenance, have prevented their competing on even terms with improved single-reduction motors.

Single-reduction Motors.—The maturing of the design of single-reduction motors marks a distinct epoch in the construction of tramway motors. The practical experience of many years' use has proved them reliable and efficient; and they have fairly fulfilled the following essential requirements of a motor for tramways:—

1. The motor must be as light in weight as possible, having due regard to strength and simplicity in its mechanical and electrical construction.

2. It must be completely closed in, and protected from dirt and moisture.

3. Its capacity must be ample, and it should be able to run continuously for at least two hours at its rated capacity, without heating beyond 90° to 135° Fahr. rise of temperature. It should be capable of developing at least 50 per cent. more than its rated capacity, without injurious sparking or other damage; and the starting torque or turning moment must be great.

4. All the external and internal parts of the motor must be thoroughly accessible, and easily taken apart.

That motor is the best which enables the line to be worked at the lowest cost for fixed charges as well as for running expenses. The relation between weight of motor and expense of working is forcibly shown by the maintenance of way on various tramways at present working. A motor entirely protected from dirt and moisture needs far less repairs, and so diminishes the cost of working. If a motor does not keep within a certain limit of heating and sparking, renewals of parts will obviously become numerous and costly. Difficulty of access to the wearing parts means higher charges for maintenance and labour.

Gearing.—More than one reduction in gearing between armature and axle means too high speed of the armature, and consequently too great wear in the teeth. Any decrease in number of parts and bearings diminishes the cost of maintenance. Large teeth must be used, and the gearing must run in grease. Experience has proved the greater economy of steel over cast-iron gearing for tramway motors. A recent investigation of sixty-six tramways in forty-nine cities, using over 7,000 motors, has demonstrated that the average life of cast-iron gearing is somewhat over 30,000 miles, while that of steel gearing is nearly twice as great. Apart from the advantages of longer life and higher efficiency, there is much less danger of breakage in steel than in cast-iron gearing, and of consequent springing or breaking of shafts and frames. The teeth are cut out of a solid rim by finely made cutters of the best known shape, as determined by exhaustive experiments. Motor pinions should be made from the best hammered steel forgings, and the teeth should be formed by accurate cutters and specially designed machinery with the same care as is used in the manufacture of the gearing; and they should all undergo the same rigid inspection and tests as the gearing.

Power.—The average horse-power exerted by a tramway motor at the car wheel probably does not exceed 20 per cent. of the maximum power it is expected to exert in starting the car under the various conditions encountered. In order to get the best efficiency out of such a motor, it is necessary that its point of highest possible efficiency should coincide with the development of the power at which the largest amount of work is to be done.

Suspension of Motors.—There are three principal ways in which the motors can be suspended from the trucks; they are known as "nose," and "side-bar," and "centre" suspension. In the first method, shown in Figs. 17 and 18, Plate 6, one end of the motor rests on the axle through its bearings, while the other is hung from the truck by a cross-bar and springs. An advantage claimed for this method is that the gearing wears more evenly. In "side-bar" suspension the weight is nearly all taken off the axles. As shown in Figs. 19 and 20, a side frame resting entirely on springs carries the motor by two lugs, one on either side, which are so placed that the motor is suspended from its centre of gravity. This plan has not proved as successful as was anticipated; and the first, or "nose" suspension, is still much in use. The "centre" or "yoke" suspension, shown in Figs. 21 and 22, does not differ greatly from the "nose" suspension.

Rating of Motors.—This is rather a difficult question, because there are so many variable factors. At present nearly every manufacturer has a different method of rating, and a motor which would be called 15 horse-power by one is called 30 horse-power by another. A tramway motor works intermittently, and therefore can exert for brief periods a much larger power than it could continuously. Motors may be rated either by the torque or turning moment which when making a given number of revolutions per minute they exert upon a wheel of a given diameter, that is to say, by their tractive effort; or else by the horse-power which they can develop. In both cases however care must be taken to state the length of time during which the motors are to exert their rated power; and also the rise of temperature permitted in that time. The General Electric Co., which is the largest manufacturing establishment in the United States, rates its motors by the torque which they can exert for one hour at the circumference either of a 30-inch or of a 33-inch wheel, at the speed for which they have been constructed, with a limiting rise in temperature of 135° Fahr. after a run of one hour. Such a rating fairly represents the maximum conditions of ordinary working, and leaves sufficient margin to meet emergencies without injury to the motor. Instead of expressing the power of the motor by the torque, the tractive effort or draw-bar pull which the motor can give out at the normal speed may be stated. Motors may also be rated by the horse-power which they can safely give out temporarily, while they are so designed that they can run continuously at half that rated power without their temperature rising by more than 90° to 135° Fahr. Inasmuch as all the insulation used in the construction of tramway motors is practically fire-proof, they can stand a far greater amount of heating than ordinary stationary motors. It is unnecessary to go into the electrical details of the devices used for controlling the speed with tramway motors; they can now be considered practically perfect, and they are so designed mechanically that it is impossible for an attendant to make a mistake in handling them.

Figs. 29 and 30, Plate 10, have been kindly furnished by the British Thomson-Houston Company. Fig. 29 shows, both with full and with shunted fields, the commercial efficiency, the torque or tractive force at the circumference of a 33-inch wheel, and the speed, with a G. E. 800 motor having a four-turn armature, that is, a General Electric motor having a torque of 800 lbs. This motor was originally constructed for American lines, and is designed for average speeds of 12 to 15 miles an hour. Fig. 30 gives the efficiency, speed, and tractive effort of a G. E. 1,000 motor with full field.

Figs. 31 and 32, Plate 11, furnished by the kindness of the Westinghouse Company, give the horse-power expended and developed, the efficiency, the torque or tractive force with a 30-inch wheel, and the speed, with a No. 46 motor, which is nominally rated at 25 H.P. The temperature tests of this machine were as follows:—ampères, 38; electromotive force applied, 500 volts; duration of test, one hour; draw-bar pull with 30-inch wheels, 1,000 lbs.; rise in temperature of commutator 54° Fahr., of field 115°, and of armature 72° Fahr. For higher currents than the above the temperature will rise approximately as the square of the increase in current. But for lower currents the temperature will not fall according to the square of the decrease, because the element of iron-core loss is practically a constant, and is therefore of greater relative value at light loads.

Power Station.—The success or failure of an electric line depends to no small extent upon the situation and design of the power station. The conditions which govern its erection are in many ways entirely different from those which have to be considered in the construction of an electric-lighting station. The load is constantly varying, and the variations are large and unexpected. Breakdowns are more serious than in electric lighting; and such precautions must be taken as will render a suspension of service practically impossible under any circumstances. In many instances the station must be in continuous operation for several consecutive days. In large American power-stations certain of the engines have frequently been running for eight and ten days continuously. In Fig. 35, Plate 13, is shown a diagram of the results obtained in a series of readings taken on an English tramway; and in Table 10 are given the sizes of engines recommended for use in power stations.

TABLE 10.—*Sizes of Engines recommended for use in Power Stations.*

Maximum Power required. I.H.P.	Number of Engines.	Power of each Engine. I.H.P.
200	2	200
400	3	200
600	3	300
1,000	3	500
1,500	4	500
2,000	4	750
5,000	6	1,000
10,000	6	2,000

In early days the engines employed were far too small and weak. At the present time dynamos for tramway work are so constructed that accidents to them are quite as rare as to the driving engines themselves. Countershafts have been abandoned as wasteful in power and useless. Large reserves of power were also provided on the earlier electric lines; this practice has been abandoned, and Table 10 shows the reserve power which should be allowed; it will be seen that a sufficient number of engines are provided to furnish the maximum horse-power required for working the line, with a surplus of one engine in reserve. With this reserve the machinery can be kept in perfect adjustment and repair, one engine being at all times stationary. In case of a breakdown, this extra engine is ready to take the place of the one disabled.

Driving.—A great diversity of opinion used to exist as to whether the engines should drive the generators by belts or ropes, or be directly coupled. The great objection advanced against direct coupling was the want of elasticity, which in the event of sudden and heavy overloading might cause a breakdown of the engine itself. It is said that belts and ropes act as a spring, and prevent sudden shocks from damaging the engine. It seems however to be beyond doubt that, for large stations having direct-coupled engines of 500 horse-power and upwards, slow-speed compound condensing engines, horizontal or vertical, are preferable. Direct coupling is steadily gaining ground, and should always be used for units of 100 kilowatts and upwards.

Stations should always be built as compact as possible; but space, light, and above all, ventilation, should never be grudged in the engine room. Whether vertical or horizontal engines are adopted seems to depend primarily upon the available space; and secondly, and to a large degree, upon the fancy of the designing engineer.

Power.—Tramway work being of such a character that even in the largest stations the average load rarely exceeds two-thirds of the maximum, it becomes necessary, in order to have an economical engine, for it to be so constructed that at its most economical cut-off it will give out two-thirds of its maximum power. Thus, supposing an engine at its most economical cut-off of 28 per cent. will give

350 horse-power, at its maximum cut-off of 80 per cent. it will give 520 horse-power. When therefore an engine of 350 horse-power is ordered, it is expected to be able to run at 50 per cent. overload, the generators being constructed to stand the same strain. All bearings must be of such ample dimensions as to run perfectly cool when the engine is working at 50 per cent. above its rated power.

Engines.—In consequence of the difference of conditions between a lighting and a traction station, all engine builders who have had experience in tramway work now build an entirely different kind of engine for traction from that which they supply for lighting stations, as far as dimensions and weights are concerned, as indicated in Table 11. The conditions under which a tramway engine works are if anything more onerous than those of a rolling-mill engine. A slight variation either in number of revolutions per minute or in angular velocity per revolution is of the greatest importance in a traction station, whereas it is of small importance in a rolling mill. A traction station should always be so arranged that, if the normal load be suddenly thrown on or off an engine, the speed shall not vary more than 2 per cent. total, that is 1 per cent. on

TABLE 11.

Comparative Weights of Engines for Lighting and for Traction.

Power of Engine.	Weight of Engine.					
	For Lighting.		For Traction.		Difference.	
I.H.P.	Lbs.	Tons.	Lbs.	Tons.	Lbs.	Tons.
90	13,000 =	5·8	15,000 =	6·7	2,000 =	0·9
115	15,000 =	6·7	17,000 =	7·6	2,000 =	0·9
140	21,000 =	9·4	23,500 =	10·5	2,500 =	1·1
215	33,000 =	14·8	37,000 =	16·6	4,000 =	1·8
325	46,000 =	20·5	50,000 =	22·3	4,000 =	1·8
400	53,000 =	23·7	58,000 =	25·9	5,000 =	2·2
500	74,000 =	33·0	80,000 =	35·7	6,000 =	2·7

either side of the mean. In some cases a maximum variation of $1\frac{1}{2}$ and $1\frac{1}{4}$ per cent. is all that is allowed. Where polyphase currents are used, constant speed is of even greater importance; and a guarantee should be required that under no circumstances shall the angular velocity during one revolution vary more than three-quarters of one per cent., and in some cases not more than half of one per cent. With heavy fly-wheels, and governors properly designed for tramway work, especially when the governors are of the fly-wheel kind, it is quite practicable to fulfil the above conditions. A shaft governor is undoubtedly far more satisfactory in every way than any ball governor driven by belt or gearing from the engine shaft.

Governing.—During the last few years there have been several fly-wheel accidents in tramway stations in America. Respecting these accidents and fly-wheels in general, more is said later on (page 73). Most fly-wheel accidents have occurred with engines employing a releasing valve-gear and a delicate ball governor. When the load is suddenly thrown off, and when they have to work with no load and a vacuum, ball governors are too uncertain. They generally act; but occasionally the valve-gear, owing to wear or bad adjustment, prevents the engine from controlling itself. To obviate this, a second governor is put in engines of this class, which governs some ten revolutions slower than the main governor, and which, when it exceeds the speed it is set for, causes a stop-valve to trip, whereby the steam is entirely shut off from the engine. This seems to be an admission that such engines are liable to run away. With powerful shaft governors connected directly with the cut-off valves by means of positive mechanism, it is impossible for engines to run away.

Table 12 gives the standard dimensions of bearings and fly-wheels, and the weights, of typical engines now successfully working large tramway stations; the first two examples are engines with fly-wheel governors. The smaller engines are fitted with single or double piston-valves, Plates 7 and 8, and the larger with gridiron valves. In small engines the governor acts only on the high-pressure cylinder; but in large engines it is so arranged as

TABLE 12.

Weights of Engines and Fly-wheels for Electric Traction.

Description of Governor			Fly-wheel Governor			
Power of Engine	at economical load	I.H.P.	583	1,070	500	800
	maximum	I.H.P.	911	1,650	1,000	1,600
Weight of Engine		lbs.	106,000	177,000	186,000	325,000
		tons	47·4	79·0	83·1	145·0
Fly-wheel	diameter	feet	11	15	15	20
	weight	lbs.	25,000	45,000	60,000	100,000
		tons.	11·2	20·1	26·8	44·6
Bearings	diameter	inches	13	15	18	20
	length	inches	25	30	34	36
Ratio of length to diam. of bearings			1·92	2·00	1·89	1·80

to act on both cylinders. Table 13 gives the dimensions of some standard continental engines, most of which are driving rolling-mills. On comparing the dimensions of the bearings in this table with those of the tramway engines, it will be seen that the ratio of the length of the bearing to its diameter in the tramway engines is generally somewhere near 2 to 1, Table 12; whereas in the engines not designed for tramway work it is nearer 1½ to 1, Table 13. The

TABLE 13.—*Proportions of Bearings in Rolling-Mill and other continental Engines.*

Cylinder.		Revolutions per minute.	Bearings.		
Diameter.	Stroke.		Diameter.	Length.	Ratio of Length to Diameter.*
Inches.	Inches.	Revs.	Inches.	Inches.	Ratio.
17·7	27½	66	6·7	10·8	1·61 to 1·00
23·6	43	75	12·6	24·4	1·93 to 1·00
23·6 35·4	41	60	8·6	14·2	1·65 to 1·00
23·6 39·3	39	120	9·8	14·5	1·48 to 1·00
25·6	25½	105	9·6	15·7	1·63 to 1·00
27·5	39	100	10·2	16·5	1·62 to 1·00
49·2	49	85	17·1	23·6	1·48 to 1·00

* Mean ratio of length to diameter of bearings, 1·63 to 1·00.

main bearings are usually provided with cylindrical shells, which can be taken out by simply jacking up the shaft to take the weigh

TABLE 14.—*Tests of Pratt-Street Electric-Power Station, City and Suburban Railway, Baltimore.*

Date of test, 1895	August	14	16	17	21	Average.
Average Indicated Horse-Power for 20 hours . .	I.H.P.	1,860	1,873	1,773	2,000	1,876·5
" Electric " " " . .	E.H.P.	1,395·5	1,405	1,330	1,499	1,407·4
Coal used, total	lbs.	75,678	70,885	72,885	74,511	73,490
" " per I.H.P. per hour, engines only	lb.	1·83	1·70	1·85	1·67	1·76
" " " " " other machinery . . .	lb.	0·20	0·19	0·21	0·19	0·20
" " " " " entire station . . .	lbs.	2·03	1·89	2·05	1·86	1·96
" " " E.H.P. " " " . . .	lbs.	2·71	2·52	2·74	2·48	2·61

Coal Consumption.—The above consumptions are based on the total amount of coal actually used in the station for the above electric output, no deductions being made for ash, clinker, or moisture.

Load.—The heaviest load was 781 I.H.P., the lightest 366, and the average during four hours 553 I.H.P.

Generators.—Four 500 kilo-watt by General Electric Co., of 670 E.H.P. each, making 2,680 E.H.P.; and one 200 kilo-watt, of 268 E.H.P.; total 2,948 E.H.P.

Boilers.—Campbell and Zell water-tube, four sets of 700 H.P., making 2,800 H.P. total.

Engines.—Four compound by McIntosh and Seymour, cylinders 20 and 36 inches diameter by 36 inches stroke, of 750 economical I.H.P. each, making 3,000 I.H.P.; one compound by same makers, cylinders 15 and 23 inches diameter by 17 inches stroke, of 250 economical I.H.P.; stoker, hoisting and conveying engines of 50 I.H.P.; total 3,300 I.H.P.

Two Blake vertical twin air-pumps and condensers, each 1,800 H.P. capacity, making 3,600 H.P.; one horizontal ditto, 250 H.P.; total 3,850 H.P. capacity.

Two Blake duplex feed-pumps, 14 and 8½ inches diameter by 12 inches stroke, each 2,800 H.P. capacity, making 5,600 H.P.; two combined pumps and receivers, 6 and 4⅛ inches diameter by 7 inches stroke, each 4,500 H.P. capacity, making 9,000 H.P.; [total 14,600 H.P.

Hunt's coal and ash conveying apparatus. Roney mechanical stokers.

off the bearings. The shells are made hollow for water circulation, which can be used in case the bearings should heat from dirt or other cause; by this means the engine can be enabled to complete its run.

Tests.—Table 14 gives the results of tests recently made in a large American station. There are four tandem compound condensing engines: high-pressure cylinder 20 inches diameter, low-pressure 36 inches, stroke 36 inches; initial pressure 125 lbs. per square inch, economical cut-off 5–16ths of stroke in high-pressure cylinder; vacuum 24 inches of mercury; revolutions 103 per minute. These four engines each drive by belt a 500 kilo-watt generator; and there is one direct-coupled engine, with cylinders 15 and 23 inches diameter, and 17 inches stroke, driving a 200 kilo-watt generator. The results may be considered highly satisfactory. Practically the minimum coal consumption is 1·67 lb. per indicated horse-power, and 2·48 lbs. per electrical horse-power at the switchboard. It therefore appears safe in a well-designed and fairly large station to estimate the coal consumption per indicated horse-power at 2 lbs., and per electrical horse-power at not more than 2·66 lbs., so that the coal consumption per Board of Trade unit will not exceed 3·3 lbs.

Fly-Wheels.—The use of fly-wheels in electric traction stations is important. Owing to the need of keeping the angular velocity as constant as possible, especially in large stations where, through Board of Trade regulations, polyphase transmissions become a necessity, the fly-wheels have to be much heavier than for ordinary lighting work. The strains they may be called upon to bear occasionally are enormous. The dynamos for tramway work are now constructed with such an amount of copper, and with such fire-proof insulation, that they can stand short-circuiting without serious damage. Circuit-breakers are of course supplied, and are generally prompt in action; but it may happen, and has occasionally occurred, that something goes wrong with the circuit-breaker, and it will not immediately break the line when a short circuit occurs. It may therefore happen that an engine may be practically stopped dead, and enormous strains may thus be put on the fly-wheel. Moreover the moment the fly-wheel has stopped, the circuit-breaker may happen to act, and the full power behind the piston may be applied to rotate the wheel, thereby again subjecting it to great strains. The utmost care has therefore to be taken in the design of fly-wheels. Accidents cause terrific havoc, and as far as the damage done is concerned are nearly as bad as boiler explosions, if not worse. In America the circumferential speeds allowed, even with cast-iron wheels, are much in excess of those to be met with in this country or on the Continent; over 90 feet per second is frequently allowed, as seen from some of the tables, whereas in English practice it is not considered safe to go beyond 80 feet. This may possibly be owing to the better quality of cast-iron in America.

Fly-wheels built-up of rolled plates, and constructed more like a boiler or a bridge, have been adopted to some extent in electric tramway stations in America. In Figs. 26 to 28, Plate 9, are shown plate constructions of two kinds. These built-up wheels generally have a cast-iron centre or hub, with brackets to which the armature is bolted, Fig. 28, so as to take some of the strain off the two keys that hold the armature on the shaft. To the centre of the hub are connected segmental web-plates, extending to the extreme outside diameter of the wheel. The plates are faced along their edges, so as to form a good joint. Outside of these segments are two circular plates, bolted through each segment and through both plates and hub, Fig. 28. The segments are generally braced by truss pieces, held in the centre by cross bolts which act as struts. Outside the web plates surrounding the rim is a strip riveted through the rim; and outside of this is a second strip also riveted through, Fig. 28. The rims of these wheels are usually turned down after the wheels have been riveted up and fixed on the shaft.

Accidents to fly-wheels may generally be attributed to three chief causes:—firstly, poor castings or internal strains; secondly, faulty design and construction; thirdly, excessive speed. In designing a fly-wheel it is easy to calculate its parts so that it shall be perfectly safe to bring it to a stand-still within a given angle. Investigation of some of the best fly-wheels for tramway stations shows that their design permits of their being stopped in less than one revolution, with factors of safety varying from 17 to 18.

Generators.—The kind of generator to be used for electric traction is an important question. As in the case of the engines, tramway generators, Table 15 (pages 76–7), must stand heavy overloading without damage. Moreover, as one pole is earthed, the greatest care must be taken that the best insulation is used throughout. Since the loads to which they are subject are extremely variable, dynamos as usually constructed for lighting work would require the position of their brushes to be constantly altered. To obviate this, heavy magnetic inductions are allowed for in designing tramway generators, thus rendering it unnecessary to shift the brushes, and also avoiding sparking. It is the universal and best practice to use toothed armatures in tramway work.

As to the kind of field winding which should be adopted, it would seem from tests made on a large scale with separately excited, shunt-wound, and compound-wound machines, that the best suited to tramway work from every point of view is the over-compounded generator. The usual pressure of current employed on trolley lines is 500 volts; and for this tension dynamos are so designed that the pressure between their terminals is 500 volts at no load, and is increased to 550 volts when the full load comes on. The over-compounding can be regulated up to 10 per cent. by varying a german-silver shunt placed on the series coil.

The curves represented in Figs. 33 and 34, Plate 12, for which the author is indebted to the British Thomson-Houston and Westinghouse companies, show the high efficiency of tramway generators with large variation of load.

TABLE 15. *Electric Tramway Generators.*

Rated Power.	Total Weight of Generator.		Diameter of Shaft.	Armature.		
				Diameter.	Weight.	
Kilo-watts.	Lbs.	Tons.	Inches.	Inches.	Lbs.	Tons.
150	13,100 =	5·8	7 to 9	45	6,000 =	2·7
225	37,000 =	16·5	9 to 11½	59¼	14,520 =	6·5
	34,300 =	15·3	9 to 11½	59¼	13,920 =	6·2
	21,000 =	9·4	9 to 10½	45	7,000 =	3·1
300	60,400 =	27·0	14 to 16	59¼	20,720 =	9·3
	43,900 =	19·6	14 to 16	59¼	16,650 =	7·5
	39,100 =	17·4	14 to 16	59¼	15,500 =	6·9
400	74,250 =	33·1	15 to 18	72	31,480 =	14·0
	71,440 =	31·9	15 to 18	72	30,580 =	13·6
	64,300 =	28·8	15 to 18	72	28,740 =	12·8
	59,700 =	26·6	14 to 16	65½	24,900 =	11·1
500	87,150 =	38·9	16 to 18	88½	35,800 =	16·0
	76,000 =	34·0	16 to 18	88½	32,000 =	14·3
	71,300 =	31·8	16 to 18	88½	30,500 =	13·6
	64,300 =	28·8	16 to 18	88½	27,100 =	12·1
800	110,000 =	49·1	19 to 22	94½	49,440 =	22·1
	100,900 =	45·0	19 to 22	94½	45,520 =	20·3
	94,400 =	42·2	19 to 22	94½	41,170 =	18·4
1,300	158,930 =	71·0	24 to 27	126	69,910 =	31·2
1,500	163,200 =	72·5	24 to 27	126	73,100 =	32·6
250	40,000 =	17·8	12 to 14	60	15,000 =	6·7
400	60,000 =	26·8	16 to 19	75	25,000 =	11·2
500	90,000 =	40·2	18 to 21	80	30,000 =	13·4
800	125,000 =	55·8	21 to 23	90	40,000 =	17·8
1,200	195,000 =	87·1	23 to 25	115	65,000 =	29·0
1,500	240,000 =	107·0	24 to 27	130	70,000 =	31·3

Electric Tramway Generators. TABLE 15.

Number of Poles.	Revolutions per minute.	Commercial Efficiency.			Rated Power.
		Full load.	Half load.	Quarter load.	
	Revs.	Per cent.	Per cent.	Per cent.	Kilo-watts.
6	200	93½	92½	89	150
6	120	93¾	93	89½	225
6	150				
6	200				
6	100	94	93	89½	300
6	150				
6	200				
8	80	94	93	89½	400
8	100				
8	120				
6	150				
10	75	94	93	89½	500
10	90				
10	100				
10	125				
10	80	94½	93¾	90	800
10	100				
10	120				
12	80	95	94	90¼	1,300
12	75	95	94	90¼	1,500
	100				250
	90 to 100				400
	90				500
	80 to 90				800
	80				1,200
	75				1,500

Discussion, 4 *November* 1897.

Mr. R. E. CROMPTON said, although the paper had put in so clear a form the results of so much American experience, yet this had been done so often, and the fact of electric traction having for various reasons been kept back in this country was such a sore wound to English engineers, that they were rather tired of hearing of the American practice. When public authorities forbade the payment of anything but trades-union rates of wages in this country, and at the same time accepted the lowest tenders in the form of American goods which had not been worked under union rules, it was about time for something to be done to improve matters. Against the Americans, who had achieved notable success in their electric traction, he had not a word to say; but whenever the local authorities of this country came to their senses, he thought English engineers could do the work just as well. From the very nature of the circumstances, their own experience, which was considerable in other branches of electric and mechanical engineering, was necessarily limited in regard to this particular branch; and they could only listen attentively to what had been done on the other side of the Atlantic, hoping that they might be able themselves to do better things when they had the chance. Nevertheless there were certain parts of American practice which English engineers were already able to criticise to a certain extent.

For electric traction it was said in page 69 that it was considered requisite to have a widely different kind of engine from that used for electric lighting. Although he knew Americans held that view largely, he thought there was no reason for its being taken as correct. Again it was not true that the consequences of a breakdown in an electric-traction station were more serious (page 67) than of a breakdown in an electric-lighting station. The breakdown of an electric-lighting station might be attended by a panic in a theatre, and the loss of hundreds of lives. What happened if a car service were stopped for a few minutes? The passengers growled and grumbled, and then the cars went on again. English engineers he thought had been able to show the Americans something with regard to electric lighting. In the city of Brooklyn it was not until they began to copy the English system of applying accumulators in parallel with the generating plant that they discovered for the first time what really steady electric lighting could be: so that their own engineers had said that they were then able to go to the theatres in their own districts without being ashamed of the lighting. This showed that in that branch of their profession there had been something which the Americans could learn from this country. There was no doubt however that the boot was on the other leg in regard to electric traction. The Americans had had such a long start that English engineers would have everything to learn from them with regard to the equipment of the road. But in the portion of the work which they did understand, namely the engines, he thought they would not follow the American practice, although there had been a strong attempt to thrust that practice down their throats, even for the few jobs of electric traction which had thus far been carried out in this country. In instances that he had known of, where the English practice of high-speed engines had been adopted, these engines had subsequently been turned out, and other engines of American design, slow-speed and with heavy fly-wheels, had been substituted. That he considered was a retrograde step. Thanks to the great men whom this country had produced—such men as the late Mr. Willans—English engineers had been placed in a highly favourable position with regard to the generation of electric power; and he need hardly do more than point to the results presented in Table 14, which the author said in page 73 might be considered highly satisfactory. These were not results that he should be proud of; in England he considered electric-lighting engines had already done a great deal better, and the same he thought would be the case with electric-traction engines. The only reason why the future electric-traction engines would do better here was that he believed this country could design and manufacture both better steam engines and better dynamos. In the steam-engine practice which had been described in the paper he did not see anything that he desired to copy.

(Mr. R. E. Crompton.)

The construction of the trucks was a highly interesting matter, and he should like to see drawings of the latest forms of trucks with extremely long overhang of car (page 56). It seemed to him a great achievement to have succeeded in making trucks which would carry cars of such a length as from 32 to 35 feet with such a short wheel-base as only 7 feet.

His remarks he hoped would not be taken as in any way unfair to American engineering, but simply as drawing attention to the fact that English engineers had not yet had a chance in electric traction. As soon as they had that chance, which he believed would happen shortly, they would be able to show something quite as good as what had been described in the paper.

Professor W. E. AYRTON could confirm what had been said in the paper about the extraordinary development of electric traction in the United States, whence he had just returned. At one electric-traction motor works that he had visited they were turning out on an average over 200 car motors complete per week, of about 25 H.P. each, and in some weeks they turned out 500. As many as 800 car motors he had himself seen being packed ready and put on the ordinary street railway cars. These were figures which could hardly be understood in this country—such an output as 500 complete motors in a week for so-called street railway cars. The effect which the street railway system was there producing, not merely in the towns but in the suburbs, was extraordinary. He had himself travelled on a street railway no less than 35 miles out of Boston at a speed of probably about 12 miles an hour, along country roads, going from house to house, past dwelling-houses and farms, through villages, then through towns, sometimes through a wood without a house in sight, going up hill and down hill; and going as fast up hill probably as a horse could gallop down hill, for the simple reason that when the car went up hill it had practically the whole power of the central station to propel it: much the same as if, when an ordinary horse vehicle came to a hill, it found fifty or sixty horses waiting to pull it up. To this traffic a small portion of the width of the road was given up entirely, and had become over-grown with grass, because no horses went there at all, the rails running along the side of the road and a trolley wire overhead. The rest of the road was used for ordinary traffic, or for what there was left of it. One thing that struck him greatly, as showing the extraordinary development which had taken place, was that, as far as he could remember, electric tramways in Boston had only been started as recently as 1888 or 1889, and yet the main generating station had been twice completely remodelled. At first the central station had been put up, equipped with fifty 100-H.P. dynamos driven by belts from the engines, and with all measuring instruments, switches, and other appliances. There it was today entirely unused; for after a year or two it had been found quite hopeless to work Boston with a little central station like that, with only fifty 100-H.P. dynamos. An entirely new station was then built, for which the unit taken was 300 kilo-watts, or roughly 400 H.P.; and it was entirely fitted up with different engines, still however driving the dynamos by belts. In two or three years it was again seen that this was no longer sufficient; and now a third station was running, in which the unit was 2,000 H.P., and there were ten such dynamos, each coupled direct to a separate steam-engine, on the plan which had been learnt from England, as mentioned by Mr. Crompton. And this Boston station was only one of six generating stations in the town for supplying current to the electric tramcars.

Besides the many important reasons given in the paper why the car truck was quite distinct from the car body, one other reason was the practice which existed in some towns, such as Montreal, of changing all or most of the car bodies from summer to winter. When the summer ended, all the open car bodies were taken off, and winter cars were put on, which were warmed electrically. The car truck with the motors was for both winter and summer; and therefore there was a great saving in expense by having the car body separate from the truck.

The diagram, Fig. 35, Plate 13, like so many which had been exhibited on previous occasions, showed the great extent of fluctuation in the current on an English tramway. But that was not what he had seen in the States. When watching the ammeters in

(Professor W. E. Ayrton.)

some of the large American stations, he had seen no such fluctuations as these. The output was something like 10,000 ampères, at a pressure of 500 volts; and owing to the current being so large and to the great number of cars constantly driven by it, the stopping and starting of a single car, or of two or three cars, produced hardly any effect at all on the current sent out from the station. So far from the ammeter needle oscillating backwards and forwards, it hardly moved at all during the time that he watched it minute after minute. There was of course a slow motion one way or the other, as the traffic of the day became greater or fell off; but as far as he had seen there were no such fluctuations at short intervals as were here shown. The reason was obviously that, where there was so large a current and so great a number of cars, the average number running along the level and uphill remained practically constant.

In England there had been an idea that the trolley wire running overhead was a terribly ugly thing, and would quite spoil not only the towns but even the country roads. This he thought had been one of the reasons why English people had objected to the use of electric tramways with overhead trolley wires. Not long ago there had been a suggestion to put up one somewhere in the more distant suburbs of London; and when the suggestion came before the London County Council, it had been received with derision as spoiling the roads with such an abomination as a trolley wire. But when a trolley wire was actually seen, it did not strike the eye as being so ugly. In Canada and the United States there were already telegraph, telephone, electric-lighting, and other wires, which owing to their number and arrangement were undoubtedly ugly; but the trolley wire was only a single wire, or at most a pair. In Tottenham Court Road and other main streets in London there were posts up already which were used for electric lighting; and in the Euston Road, Regent Street, Piccadilly &c., there were lamp posts all along in the middle of the road. Euston Road was perhaps too narrow for electric traction; but how about Regent Street? what eye-sore would it be to connect those posts together with a light wire overhead? That would be all that was wanted to serve as a trolley wire for an electric tramway. If the residents objected to this, London was rich enough to go as far as adopting what had been done in New York, where he believed that 75 miles of conduit would soon have been laid underground for electric tramways, with two insulated conductors in the conduit; there was thus no trolley wire at all, and nothing was seen in New York, in connection with the electric tramways, but such a central groove or slot as was already seen in this country wherever an ordinary wire-rope tramway was working. Although it was sometimes said that such a plan would be unsuccessful, because water and slush would get into the conduit and there would be short circuits, yet that plan was actually better, although of course much dearer, than the few trolley-wire systems already in use in this country, because both of the conductors in the underground conduit were insulated, and there was no risk of interfering with the telegraph or telephone wires overhead. The underground conductors produced no electrical disturbance of any kind. There was no risk of electrolysis damaging gas-pipes or water-pipes by corrosion. As to whether it would prove commercially successful or not, some four years ago he had been to see the same plan in operation in Washington, where there had then been already four years' experience of it, and it had been found to have succeeded. That was why it had subsequently been adopted, and to so much vaster an extent, in New York. If therefore English vestries with their aesthetic tastes seriously objected to spoiling the picturesqueness of the roads by permitting the use of trolley wires overhead, there was this alternative, of doing as had been done in Washington and New York, laying an underground conduit with two insulated wires. But at any rate electric traction should be adopted. Without going over to America, the trolley-wire system could be seen at work in Rouen, Brussels, and other continental cities; and he thought any one who had had the opportunity of seeing it in operation there would conclude that it was not so hideous after all.

Mr. JOHN S. RAWORTH, having a large stake in the interests of electric traction in this country, desired that the enormous amount of money about to be spent in that direction should be

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spent economically, and that the shareholders and municipalities should derive a good return for their outlay. Into the present paper it seemed to him that a large number of opinions and statements had been introduced, which were not backed up by evidence or reason; and he feared they might have the effect of occasioning a great waste of public money, by causing electric tramways to be worked at a much higher expenditure than was required by the nature of the work. The views put forward in the paper in regard to steam engines he hesitated to accept as the author's own, because he had noticed that the same opinions had been reiterated in the American technical periodicals during several months past. From Professor Ayrton's remarks he gathered that the Americans were on their way towards ultimately arriving perhaps at truth by a system of trial and error; they seemed to have done a thing wrong one year, a little less wrong the next year, better the third year, and some day they might get to what was right. But in order that their opinions might be of any value, it must be known exactly how far they had advanced in the path of development.

In page 68 it was stated that the great objection advanced against direct coupling was the want of elasticity, which in the event of sudden and heavy overloading might cause a breakdown of the engine itself; and it was said that belts and ropes acted as a spring, and prevented sudden shocks from damaging the engine. Conformably with this view it was further stated in page 69 that the engines were now being built differently for electric traction from those for electric lighting, in order to resist the shocks they received in supplying the power for electric traction. He was satisfied however that there were no such shocks as were represented, and that a steam engine supplying electric power could scarcely receive any shock at all. The engines generally used for electric traction were automatic-expansion engines, and the one only shock they had to resist was the sudden inlet of the steam when the main valve opened at every stroke; if they could stand this, they could stand anything. Nothing could be done at the fly-wheel of an engine to increase the boiler pressure; nor could anything be done in the way of reduction of speed by load that would increase the amount of stress put upon the working parts in bringing the piston to rest at the end of every stroke. These stresses were what the steam engine had to undergo throughout its daily work; and if it could not stand these, it would be unable to get through its work. Again there was one thing liable to occur in electric traction which was not met with in ordinary traction by a locomotive, namely an abomination called a short circuit. It seemed to be sometimes supposed that a short circuit was something like running up against a solid wall, which would produce stresses that would break anything. But electrical engineers knew well enough that a short circuit could not by any possibility absorb more energy than was being put into the dynamo which was supplying the energy for the short circuit. If it was only the steam pressure on the piston of the engine that was producing the power for supplying the energy, it was known exactly how much it could produce. But if the power was to come out of the fly-wheel, it might be any amount that the fly-wheel was made to suit: that is to say, the larger the fly-wheel, the larger would be the amount of power and the shock; the smaller the fly-wheel, the smaller would be the power and the shock; so that, if there were no fly-wheel, there would be no shock. This plain argument he thought could not be got over. Whence he was led to the conclusion that for electric traction a steam engine should have no more fly-wheel power than was necessary to make it work smoothly and perform its motions properly. The heavier the fly-wheel put upon it, the more would the difficulties and dangers of working be increased. Consequently it was natural enough to read in page 74 of the great trouble experienced in the United States from the bursting of fly-wheels; whereas the fly-wheels would not have burst if they had not been there.

The importance of governing an engine for electric traction so closely that the speed should not vary more than 1¼ to 1½ per cent. (page 70) was a point which he did not understand. A tramcar in which he was riding the other day had been detained for some minutes by the slowness of an awkward passenger who wanted to alight, and who would not be hurried by the impatience of the rest of the passengers. Yet the engines for electric traction it was said

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must run within 1½ per cent. of uniform speed. This was not asked for in electric lighting; although, even if the variations of the electric-light engines were so small that they could not be seen either in the voltmeter or in the tachometer, yet they could be detected in the light by the eye, which could suffer pain from minute fluctuations of the light, due to fluctuations of speed that were not visible in either of the two meters. Nevertheless for electric traction it was asked that a much higher degree of regularity in turning should be achieved by the engines than had been found necessary for electric lighting. The American engineers seemed to suppose that great fly-wheel power was wanted in order to get over sudden increments of stress or sudden demands for power; and yet they stipulated that the fluctuations in speed must not be more than 1½ per cent. How was it possible to draw upon the fly-wheel for power, without thereby reducing the speed of the fly-wheel? In order to take any power out of the fly-wheel, its speed must be reduced in the act; and yet the speed was not allowed to be reduced. What then was the good of the fly-wheel? In this matter the practice in this country was a long way ahead. Here as much as ten years ago it had been recognised that in electric lighting some fluctuation in the speed of the engines must be allowed; and it had therefore been decided to over-compound the dynamos, not only for the losses in the dynamos and in the leads, but also for the loss in the engines. This had been successfully accomplished, and engines and dynamos could now be procured which would combine all the fluctuations together in such a way that these would cancel out, and the light would be steady all the time, a uniform pressure being obtained with irregular driving. For electric traction, if desired, exactly the same plan could be carried out. The dynamos could be over-compounded 6 or 8 or 10 per cent., and the over-compounding would bring up the volts, so that there would be no fluctuation in the voltage of the current; while the fly-wheel would take up and give out power, exactly as it was required.

With reference to the bearings, he gathered from page 71 that it was considered the bearings of engines for driving an electric-traction station should be longer in proportion to their diameter than the bearings of ordinary engines, like rolling-mill engines or electric-lighting engines; and further that the length of the main bearings should be about twice their diameter. These recommendations he presumed were meant to apply to horizontal engines with over-hung crank and only one bearing; and Table 12 gave a ratio of length to diameter, ranging from 1·8 to 2. In this country ordinary electric-lighting engines that he was responsible for had a bearing on each side of the crank, and the length of each bearing was 2½ times its diameter. Consequently the total length of bearing to carry the crank was five diameters. For electric lighting he considered engines could not be made too good. The electric-lighting engines made on these lines by any of the good firms in this country were perfectly good for doing any traction work required.

Mr. E. J. Chambers inferred, from the description given of the way in which the standard tubular poles should be built up (pages 48–50), that it represented the American practice in this particular, with what had been called the SSS joint, that is—solid, swaged, and sweated. In this country however a pole could be produced in one length from the cast-iron base, and taper, which would be far better than that obtained by the SSS joints. Prior to hearing a description of them, he had imagined that the joints were intended to facilitate transport; because conveying poles 25 feet long by rail, unless a lot of them were sent together, was a most expensive matter. But when he learnt that the joints had to be solid, swaged, and sweated, it struck him that this construction was rather a mistake. Although he doubted whether it was necessary in many cases to make joints in these poles, he was himself responsible for a jointed pole, which after the christening of the others might be called the TTT, that is—taper at the joint, turned at the joint, and tight at the joint. Poles so jointed, which could be taken apart for transport, he was sure would fulfil all the conditions that were laid down in page 50 for the poles that had been described. Although he believed the TTT joint to be an excellent one for such poles, there were plenty of tube makers in this country who would make a taper pole of the full length required, and of any thickness up to 5–16ths or 3–8ths inch, which would show a

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much better curve under the heavy strains required to be borne, and would be made at much less cost than the jointed poles described in the paper.

Mr. H. Graham Harris doubted whether the full meaning had been appreciated of the test to which the SSS poles were subjected. It would be seen (page 50) that 10 per cent. of the poles were taken, and if three of these failed, the whole were rejected; presumably therefore if only two failed, the whole would be accepted. It appeared to him quite possible therefore that a number even exceeding 20 per cent. of the entire lot might fail to stand the test, if subjected to it, and yet the whole might have to be accepted. Furthermore the test described in the paper was not by any means a severe one; and in his opinion the pole with turned joints, described by Mr. Chambers, would stand a much more severe test.

Mr. W. M. Mordey, while admiring the great progress made by American engineers, and acknowledging that there was a great deal to be learnt from them, thought it ought not to be taken for granted that everything they did was right and could not be improved upon. As a matter of fact he had observed that in their anxiety to go ahead they had always gone ahead so fast that in a short time they had had to go astern almost equally fast. What were put forward as standards in American practice were not standards at all. They appeared as standards for a time; other standards were always being got out to replace them. Such changes were often made, he believed, in order to satisfy the American longing for something new; they did not by any means represent improvement, only dissatisfaction with what had gone before. The latest and most significant feature of American traction work was presented in the extensive repairing shops, which led him to anticipate that a few years hence American traction methods would be considerably modified. If the traction companies and municipalities of this country wanted to fit up stations three times in a few years, he thought they could not do better than copy what Professor Ayrton had reported as having been done in Boston (page 81). When in America a few years ago he had himself visited the electric-traction station in Boston, and had there seen the preparations for the second stage of that work. On venturing to point out that the system which was being adopted would in England be regarded as obsolete even before it was started, he was assured that it was the system of the future, and that all large electric-traction stations would ultimately be fitted up in that way: that it was the very best system, developed from their extensive practice. Yet a short time had seen much of the contents of that costly station swept away. In that instance at any rate change was not a proof of the progressive character of the work. It could not be said that the development had been so rapid that larger and larger units had been required, and that the smaller ones had had to be put aside; for he understood the engines remained the same size. It was not even want of foresight, for the present needs had been clearly foreseen. It had simply been inconsiderate action. Progress no doubt came out of such a method of trial and error; but it was a method to be avoided here. Exactly the same kind of thing, he remembered, had happened in regard to electric lighting. English electrical engineers had been long urged to emulate their American brethren, who had put up electric-lighting stations in great numbers before English engineers had seriously begun to move. In this country it was not until the business men and the municipalities had become convinced they could attain commercial success that the work was gone on with. Meanwhile the earlier and less satisfactory American work was all or nearly all being replaced. Admiring as he did the energy of the American engineers, and believing there was much to be learnt from their experience, he welcomed the little band of able and active men, who had come over to the present assistance of this country; but he thought there seemed at present to be some danger that caution might be forgotten. Those therefore who were considering the subject of traction in this country would do well to look at the great changes which had occurred and were still constantly taking place in American practice, and to see how some plans had been discarded and others adopted, not once only, but two or three times.

Adjourned Discussion, 10 *February* 1898.

Mr. MARK ROBINSON considered that any one who brought authentic information about what was being done elsewhere, perhaps better than in this country, deserved the best thanks of the Members. But when an author held up foreign models for imitation, there was sometimes a danger that, having studied them on the spot and being strongly impressed with their advantages in some respects, he might by indiscriminate recommendation unwittingly do injustice to his own countrymen, and even inflict injury upon them and upon their industries; and it seemed to him that there was some chance of such a result in the present instance. English engineers were well disposed to learn from the Americans in matters of electric traction, because the latter had had much greater experience; but there were many continental and even some English examples which were not to be despised. The present paper dealt largely with matters of which he had himself no special knowledge; but with regard to what was said in it about steam engines, he for one had no hesitation in asserting that English engine builders would be wrong to go to America for guidance in any portion of their dynamo-driving work. The discussion in page 68, respecting the advantages and disadvantages of direct driving and of belt or rope driving, seemed appropriate to an American rather than to an English paper; and the conclusion that direct coupling was "steadily gaining ground, and should always be used for units of 100 kilo-watts and upwards," seemed a little out of place as information for English engineers. It might be thought that this was a discovery which had been made in America, and worked out there; whereas the fact was that direct coupling was essentially the English plan, and had been the English plan for many years past, and it had only been slowly and grudgingly adopted in America, in the face, as he imagined, of strong interests pulling the other way. This he said with full knowledge that the first, or one of the first, of the large electric-lighting installations in England was of American origin and was direct coupled.

In page 69 it was said that engines for traction work should be essentially different from those for lighting stations; and in Table 11 were given the weights of engines of the two classes which had been built in America. But, save that automatic expansion gear was a practical necessity for traction work, while it was of small value in most continuous-current stations for lighting, it seemed to him there was really no ground for difference in the engines themselves. The only difference required was in the fly-wheels, which for electric traction should be as heavy as they should be for any other work involving the same great variations of load. This however was no more than an elementary fact, which was not likely to be overlooked in any country. It seemed as though the small fly-wheels usually fitted to English high-speed engines had given rise to the idea in some minds that high-speed engines were unsuitable for electric traction. But the truth was that the slow-speed engines recommended in the paper acted upon their crank-shafts with such great irregularity during each revolution, that the only way of getting tolerably regular running, even under a steady load, was to use very heavy fly-wheels. High-speed engines on the other hand, such as were ordinarily used for dynamo driving in England, ran with such regularity, in consequence of the more quickly recurring impulses upon the crank-shaft, that for some purposes they would drive with sufficient steadiness without any fly-wheel at all. In practice a fly-wheel was of course desirable, but for ordinary purposes it needed only to be small and light. If an engine so designed were employed for electric traction, naturally it did not run so regularly as was desirable; but it was just as easy to provide ample fly-wheel power for a high-speed engine as for a slow-speed. There was however one highly important difference between the two cases. Many had probably been struck, as he had been, by the prominence given in the paper to those fly-wheel accidents which had been so numerous and disastrous in America, and to the methods of building up fly-wheels whereby it was sought to avoid those misfortunes. Now it was not too much to say that the disc fly-wheel of small diameter, cast in one piece, which was universal in English high-speed engine practice, was quite exempt from danger of bursting; and this most

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valuable advantage was directly and solely due to the high speed of rotation usual in England. In page 70 it was recommended that a guarantee should be required that the angular velocity during one revolution of the engine should not vary by more than three-quarters of one per cent.; and it was stated that this was "practicable with heavy fly-wheels, and governors properly designed for tramway work, especially when the governors were of the fly-wheel kind." No doubt for a slow-speed engine this would be a good performance; but the ordinary three-crank quick-revolution engines, running in great numbers in electric-light stations in England, with comparatively light fly-wheels, varied their angular velocity during each revolution by less than one-third of one per cent., and this without the advantage of a governor "properly designed for tramway work," whatever that might mean, or even of a governor "of the fly-wheel kind." The fact was that the governor had absolutely nothing to do with evenness of angular velocity during a single revolution, unless the speed of revolution was extraordinarily slow; uniformity of angular velocity during one revolution was a fly-wheel question alone, and its introduction in connection with governing seemed to him to be characteristic, not only of the American predilection for the fly-wheel governor, but also of certain mistaken opinions widely prevalent in this country. It was not uncommon to find variation of speed imputed to bad action of the governor, when it was clearly due either to the fly-wheel being insufficiently heavy, or to an overload being placed upon the engine, in apparent forgetfulness of the fact that every engine worked with a cylinder of finite size and with a finite steam-pressure, and therefore could not give out more than a certain power, even when the cut-off was at the latest.

The idea also seemed to prevail widely that in some way the sudden variations of load, which might be looked for in electric traction, exposed the engine to special risks of damage. Assuming a governor worthy of the name, that is to say, one that at any rate would not let the engine race away, there was no foundation whatever for such an opinion. It was within his personal knowledge that there were many hundreds of high-speed engines, directly coupled to dynamos, which might be exposed with absolute impunity to the test of throwing the whole load off and on again, as fast as the hand could move the switch. There was no difficulty whatever. There had been numerous instances of such engines having been pulled up suddenly, owing to a short circuit, and no one had ever heard of their being any the worse for it. The fact seemed to be overlooked that the reciprocating parts of an engine were stopped and re-started a great many times every minute: in ordinary English practice from 600 to 900 times a minute in electric-lighting engines. What harm then could they sustain, either in themselves or in the crank-shaft, from being pulled up once more through what was by no means an instantaneous check, due to an overload or even to a short circuit? The matter had been subjected to careful calculation, and the effect could be absolutely neglected. No doubt there might be trouble at some place between the armature coils, where the brake might be said to be applied, and the fly-wheel, which wanted to run on; but this was a matter which concerned not the engine itself, but the fly-wheel; and it was the fly-wheel which was the particularly weak point in the big slow-running engines recommended in the paper. As regarded its fly-wheel, the high-speed engine was perfectly safe; while the slow-speed engine, to judge from what was said of it in the paper, was clearly much the reverse. Not much need be said, he thought, about the rather airy judgment in page 68, that it seemed to be beyond doubt that slow-speed compound condensing engines were preferable. Where engineering considerations were allowed to prevail, and not merely commercial interests, a different opinion seemed to him to be held by competent engineers in this country. The Liverpool Corporation for instance had recently ordered a high-speed electric-traction engine of 1,500 I.H.P. for their tramways; and the Bradford Corporation had ordered two engines, each of 700 I.H.P., for theirs. The only limit to the demand for such engines in this country appeared to be the capacity of the makers' works to produce them. That engineers and corporations had good warrant for so deciding was shown by the history of the smaller high-speed engines which had been applied to similar work in this and other countries. The earliest examples

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which were known to himself were three high-speed engines of about 200 I.H.P. each, sent out seven years ago to work the Hobart electric tramways in Tasmania; they had proved an unqualified success, notwithstanding that they laboured under the drawback of having very light fly-wheels. An equally good record had been won by a high-speed engine at the generating station of the City and South London Railway. One more instance which might be mentioned was that of three high-speed engines, which had been sent away a year and a half ago to supply current for the electric tramways at Liége in Belgium, in regard to which he had today received the following account from the Compagnie d'Électricité in that city:—"The three engines of 240 I.H.P. each, with automatic variable-expansion gear, coupled direct to compound-wound dynamos giving 150 kilo-watts each, have been doing excellent work at the central station at Jonfosse since the month of October 1896. They work daily from 6 a.m. until midnight without stopping. They run silently and without shock; their speed regulation is amply sufficient, and is at least equal to that of the best engines known; they require little attention, their expenditure of oil is small, and their wear up till now is nil." While therefore he wished to thank the author for the valuable facts recorded in the paper, he would suggest that there were no grounds for the pre-eminence which appeared to be claimed for the American build of engines for driving dynamos.

Mr. Jeremiah Head, Past-President, thought that the discussion upon this interesting and instructive paper, so far as it had proceeded, while it had brought out many important facts and opinions, especially with regard to the engines, had perhaps tended to be somewhat too severe upon the paper, and to some extent was not free from a suspicion of irrelevancy. As an electrical engineer no one had earned a higher reputation than Mr. Crompton, who, besides giving valuable information, had expressed the opinion (page 78) that electric-traction work could be done just as well by English engineers as by American. No doubt the American engineers themselves would all agree with this opinion. Then with regard to the engines, Mr. Crompton thought the American practice would not be followed here. Naturally if the American practice in engines was not right, not only would it not be followed here, but nowhere else where electric traction was employed. The belief had also been expressed (page 79) that this country could design and manufacture both better engines and better dynamos. From this belief it might perhaps be expected that American engineers would differ. A little caution might reasonably be felt when it was remembered that in America there were in 1895 more than 12,500 miles of electric tramways at work (Table 1), while in Great Britain and her colonies at the end of 1896 there were only 167 miles (Table 2). Remembering that the Americans had been working at this subject for at least ten years, several years before English engineers began to touch it at all, credit might be given them at all events for knowing something about the matter; and therefore their opinions and practice were entitled to considerable respect. It was not altogether the fault of English engineers that they had not gone ahead with electric tramways as the Americans had done. The circumstances of the two countries were totally different. It must be remembered that the United States were as big as Europe including Russia proper; and except in the towns and cities themselves there were practically no roads at all, such as in England would be called roads. England was wonderfully well supplied with roads, which had been made or re-made in the early part of the present century in almost every possible direction. An American city spread over perhaps ten or twelve times the area of an English city with the same population; it was therefore not crowded up. This circumstance and the absence of roads had latterly forced upon the residents the necessity of finding some better way than they had before of getting about; they had therefore begun with tramways, not electrical tramways at first, but horse tramways; and when horse tramways had been laid down in various places, the next step had been to work them by various mechanical means, including electricity. In 1890, eight years ago, when he had first visited the United States and studied the matter at all, there were five modes of traction on the tramways: by horses, by steam locomotives, by ropes, by trolley cars, and by

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accumulator cars. At that time it was not settled which was the best of these five plans. By this time, as seen from the statistics given in the paper, almost every plan on a large scale had disappeared, except the trolley car; and it was due to the Americans to say that they had settled the question under their particular circumstances. In this country however it was scarcely yet settled. In Newcastle-on-Tyne there were tram lines throughout the city; and when recently the power for driving the tramcars was under consideration, he believed that the city engineer had actually recommended the adoption of rope traction as the best plan. He had the greatest confidence however that either a visit to the United States or a serious investigation of their tramway statistics would result in discarding rope traction in favour of the trolley plan. The latter had some important advantages, which were scarcely realised until the plan had been practically studied in other countries than this. With regard to speed, for instance, Professor Ayrton had mentioned (page 80) that he had travelled 35 miles outside the city of Boston on an electric tramcar at 12 miles an hour. The speed however could be much greater: he had himself travelled on a line 36 miles long, which ran from the city of Cleveland to the town of Akron; and in the most rapid part of the journey the car was actually travelling at the rate of 36 miles an hour. The line was divided into four sections, each supplied with current from a separate power-house. The cars were carried on two bogies, so that they ran easily round sharp curves; they went up hill and down dale, without any attempt at cuttings or embankments. There were two motors, driving the two axles of one bogie and placed between them. The brake was pneumatic, actuated by compressed air at a pressure of 25 lbs. per square inch from a reservoir, in which the supply was kept up by an air-pump driven by an eccentric on one of the axles. A whistle also was connected with the same air reservoir. Sixty passengers could be carried in each car. The tramway rails weighed 60 lbs. per yard, and the joints were crossed, that is, they alternated on opposite sides of the road, and they were fished and bolted. They were also carefully bonded with copper connections, so as to make the rails act as perfectly as possible as return conductors. There were no fences along the roadsides at all. In the cities these bogie cars ran round any street corner, that is, the tramway curves were laid round any street corner; the cars certainly pulled up a little when they came to the curve, lest their momentum should throw them off on the outer side; the exigencies of the ordinary traffic did not admit of the outer rail being raised as on a railway. Trolley cars went up almost any ordinary ascent; he had been up a rise of one in ten himself, and in Montreal he believed they went up as much as one in seven; but of course with such steep gradients it became necessary to drive all the axles. Electricity drove the car, stopped it, lit it, and warmed it; and even the little bells fitted in the car for calling the attention of the driver were worked by electricity. In local traffic, that is to say from the centre of any city to about ten miles outside, the tramways were beating the main-line steam railways out and out; that was simply because of their facility for stopping and starting and picking up, so that they could convey a passenger almost from the very door of the house where he lived in the suburbs to the door of his office in the city, and this at brief intervals, and quicker than he could perform the journey in any other way. The average speed including all stoppages was about nine miles per hour. He was not one of those who would advocate putting trolley cars in London streets; London he thought was about the worst place in which to start such a plan. It was becoming more and more conclusively proved that where there were narrow or crowded streets there was nothing like a good pavement and vehicles that could move about in any direction, like the new electric cabs; and if tramways were to be brought from suburbs into such a city, they must dive down along an underground line, or some plan of that sort must be resorted to. But for suburban traffic, where there was a good population and where the roads were all built up along both sides, he thought there was nothing like an electric tramway. No doubt Mr. Raworth was right (page 84) in regarding American progress as a good deal due to a system of trial and error; and he would have been equally right if he had applied the same criticism to the progress effected in any other countries. No one could look at the earliest locomotive

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as it stood preserved in Darlington station, and at the express engines of the present day, without being impressed with the vast difference, and without realising that it had been brought about to a large extent by trial and error.

It was a remarkable achievement to have got a 35-foot car on a wheel base of only 7 feet; and it was astonishing to see how large a load of people those long cars carried, not only inside, but sometimes hanging on the steps all the way, and on the two ends; and how they could run at such a high speed and with safety, and how they swung round the corners of the streets. Naturally they were not altogether without some disadvantages: for instance, the noise the gear made as they started and stopped, and the noise of the trolley running along the wire, was rather distracting to strangers until they became a little accustomed to it; the noise was certainly very loud indeed, especially at night, the sound being reflected between the houses on opposite sides of the streets. When electricity first began to be applied to tramway cars, they did not answer well, because the power applied was far too small. From the experience of horse cars it had been argued that, if a pair of horses were enough to pull a car, a 2-horse-power motor ought to be sufficient to do the same work; but it was soon found that this would not do at all, because neither had the required facility of starting been sufficiently taken into account, nor the much greater speed at which the electric cars were wanted to travel. No good result was arrived at until the power of the motor was brought up to at least 25 horse-power.

From Table 14 it would also be seen how economical was electric traction, inasmuch as it appeared that at the central station the coal used per indicated horse-power per hour was under 2 lbs. on the average for the entire station, including all the steam that was used in that central station. If all the power for working a tramway system spreading throughout a large city, perhaps more than a dozen miles in diameter, could be brought from central stations like this, where the generating machinery did not consume more than 2 lbs. per indicated horse-power per hour, he thought it must be seen that the electric trolley-wire system on the whole was a highly excellent one. He thought therefore that

English engineers were much obliged to the author for bringing this matter before them so well as had been done in the paper, and that in this country there was not so much occasion to criticise details of engines or other machinery, because there was no doubt that engines and machinery were constructed here by various makers which would do perfectly well for generating the power, perhaps even better than those that were employed in America. But what was wanted to be kept in view in this country was the general question why there was such a marked difference between the mode of progression adopted in the United States and on the Continent of Europe, and that prevailing here. The means of getting about in those countries were in his opinion wanted to be a good deal more used here than they had been as yet.

Mr. W. Worby Beaumont thought that, while many might have been attracted by the title of the paper to study its contents, they would hardly have expected to meet with so much that seemed to him in the nature of platitudes or that might be found in certain catalogues. Had the title been "Some American mechanical features of American electric traction," this would possibly have been a more accurate description of its scope. While all were anxious to learn, English engineers were not always willing to accept a dictum as to what was good practice and what was not. They were accustomed to think that at all events they knew how to make engines that would drive rolling-mills, which were here likened to electric machinery for tramways; and they could equally well make them for the other class of work, namely electric lighting. It would be well to remember that they might have their own opinions with regard to what might be necessary for English electric tramways. As to why it was that there were so many hundreds of miles of tramways in the United States and so few here, he thought that to a great extent English people might answer that it was because they knew better. Firstly, these tramways had not been so much wanted hitherto in England, because here there were roads such as did not yet exist in America. Secondly, in England there had not arisen in every direction the opportunities which had

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been seized in the United States for adopting mechanical aids to finance as means of developing the value of land outside cities to the utmost possible extent.

With regard to the use of slow-speed engines fitted with heavy fly-wheels, it appeared from page 74 that serious fly-wheel accidents had happened in tramway stations in America. Not long ago he had met with accounts of those accidents happening almost every week; and they were sometimes exceedingly costly. The fact that they had happened so frequently was proved by the ingenuity which had been displayed by American engineers in since designing wooden fly-wheels, boiler-plate fly-wheels, and wire-wound fly-wheels. Yet it was stated in page 74 that a circumferential speed of over 90 feet per second was frequently allowed, whereas in English practice it was not considered safe to go beyond 80 feet; and it was added that this might possibly be owing to the better quality of cast-iron in America. In other words, one-eighth was added to the speed which was adopted in English practice; then the fly-wheel went all to pieces; and this was cited in proof of the superiority of American cast-iron.

Then with regard to the stresses brought to bear upon the engines. If the engines, as pointed out by Mr. Raworth (page 85), were capable of withstanding the stresses that naturally came upon them in the ordinary performance of their work, they must be capable of withstanding those that came upon them through any of the accidents which might happen, unless it were the falling of some heavy obstacle into the fly-wheel pit in the station. In the event of short-circuiting, all the pressure brought to bear, and the resistance that had to be overcome by the moving parts of the engine, or in other words the inertia stresses, were not any greater than the engines had to bear by the mere admission of the steam upon the piston to produce the speed at which they ran.

In explanation of the success of electric tramways in the States, running in competition with railways, it should be borne in mind that railways ran to certain stations which were more or less distant from the cities and from most of their suburbs. If the American people liked to convert their streets into high-speed goods yards, or rather into badly managed railways, it was a procedure which would certainly not find favour in England; and there was no reason why tramcars should here be running about the streets at 15 or 20 miles an hour, merely to show that 60-horse-power motors could successfully be used on a 2-horse-power tramcar; nor would it be possible to have many such tramcars running through the streets, in which a large amount of room was wanted for other traffic. In London no doubt, as in many other cities in the kingdom, a great deal more facility for rapid transit was wanted than yet existed; but it certainly could not be obtained to advantage by having electric tramcars running at 12 or 14 miles an hour through the streets, nor indeed was there room for many more cars than were in use at the present time, until all horse cars were abolished.

As to progressing by a system of trial and error (page 84), and Mr. Head's suggestion (page 97–8) that it was by this very system that such wonderful progress had been made in English locomotives, it might be worth mentioning that there were locomotives running in this country even now, which had been made here thirty-five years ago, and were still doing good work. One engine that he knew of, which was at work at the present time, had been made in 1824, seventy-four years ago: so that, if the adoption of innovations had been exceedingly slow in some instances, yet when anything had been adopted it had had a reason behind it for its adoption. In this country however there were not the same reasons as in America for adopting 50-horse-power tramcars in the streets and suburban roads, or they would have been adopted before now.

Sir Frederick Bramwell, Bart., Past-President, said the question, why was this country so much behind the United States and the Continent in their electric tramways, had been partially answered by Mr. Beaumont; but he would suggest an addition to the answer for rendering it more complete. The probability was that in the United States, and in most of the countries in Europe, private enterprise was not checked by acts of parliament which compelled the proprietors of tramways at the end of twenty-one years to sell the fruits of their industry and enterprise for the price of old metal,

(Sir Frederick Bramwell, Bart.)
in that way discouraging them from the honest exercise of their industry and capital.

Professor W. Cawthorne Unwin pointed out that in this country there was very little practical experience of the trolley system of electric traction for tramways. There were a few tramways so worked, of which one or two were American built. The Americans had had a large experience of the plan, and were carrying it on upon a scale such as English engineers had as yet no experience of here, and with a remarkable degree of success. Having been more than once in America, and quite recently, he fully appreciated that conditions were there met with, favourable to the trolley system of electric traction, which did not exist at all in this country. The first condition was that the population in an American town was spread over four or five times the area of an equal population in a town in this country. A second condition was that there was practically no competing means of locomotion in their towns. A third condition, which had struck him forcibly, was that there were habits in American towns which did not prevail here. In Boston five or six months ago he had noticed that the tramcars on a bright moonlight summer evening were crowded till ten or eleven o'clock at night with people who were merely taking a ride in order to get fresh and cool air. That was a habit which in our climate had not been developed; and it added largely to the receipts of the tramways. The electric trolley system was seen at its best in such towns as Montreal, where he had spent a day with the chief engineer of the tramways; or Ottawa, where he had also spent a day with the managing director of the excellent tramways there. In Ottawa there were no very narrow streets, and those which were at all crowded with traffic did not extend so much as a mile; and there were suburbs spreading out and populated thinly, but with a population who had to get backwards and forwards daily by means of a single direct line with no cross connections. A still more favourable condition in a town like Ottawa was that the cheapest possible power was obtained from the water-power of the river; and the result was that not only were the trams worked with ample power, but they were also lighted in a way in which he had never yet seen any tramcars lighted in this country. In the car in which he rode on the tramway in Ottawa he believed there were twenty 16-candle-power lamps. Moreover through the long and severe winter the cars were also heated electrically, not more economically than elsewhere, but much more pleasantly, and without too extravagant an expenditure, because the power was so exceedingly cheap. In Boston, which was much more like an English town, the conditions were somewhat different; and though he had seen Boston tramways three or four times he had never got reconciled to the ghastly appearance of the trolley wires overhead in the narrow streets. In America he had heard that for years they had been looking forward to superseding the trolley wires in such towns as Boston by some better plan. Within the last few weeks he understood there had been as many as two hundred horses lying dead in the streets of Boston, killed by the fall of tram wires; that was a pretty severe lesson as to one of the disadvantages of such a plan in a crowded city. Unless he was much mistaken, England seemed to be threatened with an attempt to introduce purely American methods of trolley-wire traction. Even so long as half a dozen years past he had found the more far-sighted American engineers looking forward to superseding the overhead trolley wires; and while he was in New York a few months ago there were between 2,500 and 3,000 men at work in the streets there, laying underground conduits for working the electric tramways. The engineers believed they had succeeded in devising a conduit system which would have none of the ordinary objections attaching to the trolley wires.

Respecting the engines employed in electric-traction stations, he thought there could be no doubt that, if the fly-wheel were the principal consideration, then short-stroke quick-revolution engines possessed great advantages, especially such as had three cylinders working on one crank-shaft. Having had some time ago to look into a question of engines for electric traction, he had found that apparently the light fly-wheels on a Willans engine were virtually as effective for the conditions under which they worked as the much heavier fly-wheels placed on some of the long-stroke engines that

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were used for electric traction in America. The fact seemed not to have been appreciated by engine builders in this country, who had been accustomed to build long-stroke engines, that, when used for the particular purpose of electric traction, long-stroke engines wanted fly-wheels much heavier than they had been accustomed to provide for the simple and regular driving of cotton mills; and on such engines as were employed in America he considered it would be unwise to use lighter fly-wheels than were being actually used on them. Having had to look into the matter, he had come to the conclusion that the way in which the long-stroke slow-speed engines were treated in America as regarded their fly-wheels was perfectly right. The statement he believed was somewhat exaggerated that fly-wheel accidents in electric-traction stations were happening almost every week (page 100); the longest list of fly-wheel accidents that he had ever seen was not American, but German. In no sort of way did it follow that because a fly-wheel was heavy it was therefore dangerous. A heavy fly-wheel might have exactly the same strength as a lighter fly-wheel, provided the rim velocity was the same. There was no reason why a heavy fly-wheel should be more dangerous than a lighter fly-wheel. It was true that, with the enterprising riskiness which sometimes characterised American engineering, fly-wheels had been built there which had a rim velocity fully twice of what, half a century ago at any rate, had been considered in this country the maximum possible rim velocity for a fly-wheel. The adoption of twice the rim velocity had involved four times the stresses; and this no doubt had introduced an element of danger. But because a fly-wheel was heavy, it was not obliged to run at 90 feet a second; and there was no reason why a heavy fly-wheel should be more dangerous than a lighter, if running at the same speed. The whole decision as to the kind of engines to be used for driving electric-traction stations seemed to him to rest on other considerations than the fly-wheel. The question whether long-stroke engines were the best for such work he thought had not been quite settled yet; his own leaning was rather in the direction of the American practice. Short-stroke engines were the most convenient, and for many purposes the cheapest; but he was by no means yet convinced that the American practice of using the long-stroke engines was wrong.

Professor Alexander B. W. Kennedy, Past-President, was in the unfortunate position of being one of the few Englishmen to whom riding in an electric tramcar in America appeared just as agreeable or disagreeable as riding in a tramcar anywhere else. He had not been in any car that was illuminated by twenty 16-candle-power lamps; those in which he had ridden were not so well illuminated; in fact their light was always going up and down in a way that was decidedly irritating. On various occasions he had had to go carefully into the general question of traction by electrical and other methods; and as far as he could see electric traction ought to be treated as a matter of general mechanical engineering, and to be dealt with on perfectly general grounds. There was no mystery whatever about it, which should entail a slavish repetition of whatever had already been done somewhere else. There was no such mystery about it; nor was there any difficulty whatever in working the dynamos for electric tramroads or electric railways with short-stroke high-speed engines just as well as with long-stroke slow-speed engines; he did not say better, because that was not now the question. Too many attempts had been made to persuade English engineers that what had been done so well and so successfully in America was the only thing that could be done anywhere else; and he considered it was high time to recognise that there were many other ways of doing the work desired, which he thought were quite as good as the way that had been adopted in America and had proved there so successful. The alleged difficulty arising from an engine being pulled up short really existed mainly in imagination. All engineers concerned with such work had tested high-speed engines by suddenly throwing the whole load alternately off and on; and for himself he might say, not only that he had done this without causing the slightest injury to any part, but that the speed indicator on the driving shaft showed barely any difference whatever. After such tests it was really futile to talk about what would happen to any particular kind of engine that was not identical with the kind which had been used elsewhere. There were plenty of good engines

(Professor Alexander B. W. Kennedy.)

which did not mind short-circuits, or anything else that might suddenly put upon them the maximum load or take the entire load off.

Mr. ARCHIBALD SHARP said a good deal had been heard about fly-wheel accidents in America; but in this country they were not unknown, for within the last two years there had occurred three accidents to large fly-wheels, one of them involving great destruction of property, in Glasgow, in Barrow, and a few months ago in Lancashire. The fortunate circumstance that no lives had been lost had proved unfortunate for arriving at the causes of the accidents, inasmuch as the fact of their occurrence was consequently known to a limited extent only. When a fly-wheel was in motion, the rim tended to expand under the action of centrifugal force; and the stresses on the rim would depend greatly on the method in which it was constrained by the mode of its construction. In a freely rotating rim with a circumferential speed of 100 feet per second, which was above the safe limit, the circumferential tension produced in the rim was only 0·47 ton per square inch of its transverse section. This he fancied must be the low figure which the author had had in mind when stating in page 75 that fly-wheels were running with factors of safety varying from 17 to 18; such a margin he thought must be erroneous. In a large fly-wheel with six or eight arms the stresses on the rim were due principally to the bending induced by the constraint of the arms. The bending moment on the rim of a fly-wheel was proportional to the centrifugal force per foot length of rim, and also roughly to the square of the distance between the outer ends of two consecutive arms. The tensile stress due to bending was probably always much greater than that due directly to the hoop tension: so that, in a fly-wheel running with a rim speed of 200 feet per second, the hoop tension just before bursting might be 1½ tons per square inch, while the maximum tension due to bending might be somewhere about 7½ tons per square inch; consequently on the section of the rim just in line with an arm there might be a maximum tensile stress of 9 tons per square inch, and a maximum compressive stress of 6 tons per square inch. Such conditions of stress were quite unsuitable for cast-iron; in fact they were nearly what would occur in a Hodgkinson cast-iron beam turned upside down. A plate fly-wheel was no doubt a good design for a large size, on account of the rim receiving practically continuous support; and in this respect it was in the same position as a solid disc fly-wheel of small diameter; but its cost must militate against its wide adoption. A fly-wheel designed by himself, and shown in Plate 14, which had been tried with a fair amount of success, was not of such an expensive construction. It had three distinct features. In the first place it had numerous spokes, so that the unsupported length of rim was small. The wheel illustrated had twenty-four spokes: so that, comparing it with a six-arm fly-wheel of the same diameter, the stresses due to bending in the rim would be only one-sixteenth—or according to Professor Unwin's exact formula* only about one-fourteenth—of those in the rim of the six-arm fly-wheel. The second feature was that the nuts at the ends of the spokes were all screwed up tight in building the wheel, whereby an initial tension was put upon each spoke, and an initial circumferential compression upon the rim. The initial compression put upon the rim should be made great enough to exceed the direct tension due to centrifugal force when the wheel was running. The third feature was that the spokes being slender must be made tangential to the hub and oblique to the rim, otherwise the wheel would not have circumferential rigidity. A direct-spoke bicycle-wheel would be an utterly unsuitable construction for a fly-wheel. A subsidiary feature of detail was the method of fastening the spokes to the hub. This was done by frictional grip alone. The spokes were made in pairs, and the middle of each pair was wrapped half round the hub, lying in a spiral groove, as shown in Fig. 38. The sides of the groove were inclined at a small angle, as shown half full size in Fig. 40, so that any desired amount of wedging action could be obtained. In the actual running of a fly-wheel so constructed of 10 feet diameter there had not been the slightest cause of doubt that this mode of connecting the rim to the hub was sufficient. The fly-wheel had been designed for a gas engine to run at 180 revolutions a minute with a circumferential speed of 94 feet per second. In default of exact measurement of the tension applied,

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* "Elements of Machine Design," twelfth edition, vol. 2, page 190.

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the endeavour was made to tighten up the spokes to an initial tension of 4 tons per square inch, which would produce an initial compression on the rim of about one-third of a ton per square inch: so that, when the wheel was running with a rim speed of 100 feet per second, the average circumferential stress on the rim would be nearly zero, while the stresses on the spokes would be increased to 4½ tons per square inch, and the stresses due to the bending of the rim would be only half a ton per square inch for compression and tension. An experiment had been made for comparing the efficacy of this 10-foot fly-wheel with that of an ordinary fly-wheel of 5½ feet diameter on the same shaft. The records of the experiment were given by the Moscrop diagrams shown in Figs. 36 and 37, Plate 13. The height of the pencil drawing the diagram corresponded with the actual speed of the crank-shaft at the instant, so that the amplitude or width of the band drawn by the oscillations of the pencil up and down was proportional to the variations of speed from point to point during the revolutions of the wheel at an average speed of 150 revolutions per minute with no load on the engine. The broader band in Fig. 36 pertained to the working of the gas engine under the ordinary conditions with two heavy cast-iron fly-wheels, each 5½ feet diameter and 1,670 lbs. weight. In the second half of the experiment at the same average speed and with no load on, represented by the narrower diagram, Fig. 37, one of the ordinary cast-iron fly-wheels was taken off, and the tangent-spoke fly-wheel of 10 feet diameter and 2,900 lbs. weight was put on in its place, the total weight of the fly-wheels being now 4,570 lbs. against 3,340 lbs. previously, whereby the speed variation was considerably reduced, as seen in Fig. 37. Approximately the speed variations in the two cases were inversely proportional to the moments of inertia of the fly-wheel rims. These two diagrams, Figs. 36 and 37, showed the effect of mere weight in a fly-wheel, as distinct from its efficacy or controlling power. The latter was proportional to its weight and to the square of the rim velocity: so that it was to the advantage of the steadiness of the engine to have the rim running at as high a speed as possible. With a heavy fly-wheel the pressure on the bearings, and therefore the total resistance of the engine, was increased, as was illustrated by the fact that with the heavier fly-wheels in action, Fig. 37, thirteen impulses per minute were required to drive the engine at no load, whereas with the lighter fly-wheels in Fig. 36 only eleven impulses per minute were required.

Mr. M. Holroyd Smith was much struck with what had not been said thus far in the discussion, in which it seemed to him rather curious that, in connection with a paper upon electric traction, scarcely any comment had been made upon the mechanical electrical details which constituted the larger part of the paper itself; nearly all the comments had turned upon some details of the engine, such as the fly-wheel. In regard to the latter he was glad that attention had again been called by the last speaker to a construction of fly-wheel which he believed had been previously advocated. Only recently he had himself been wishing to have a wheel constructed for road carriages with spokes tangential to the hub; and the idea of attaching them tangentially in the way described seemed to him such a good one that he should be glad to see if the same principle could be used for carriage-wheels as well as for fly-wheels.

Besides concurring with the reasons put forward by Mr. Beaumont and Sir Frederick Bramwell why electric traction had advanced so rapidly in the States and so little in this country, he wished to draw attention to one feature that had hardly been noticed, namely the abominable condition of the ordinary roads in the States. In one of the principal streets in Philadelphia he remembered seeing the tramway rails for lengths of twenty yards standing above the ordinary street level to a height which by measurement he had found to be fully six inches. In explanation of such a circumstance it must be borne in mind that in the States there was not any Board of Trade order requiring the use of grooved rails; the rails used in America were edge rails, somewhat similar to those used on railways, and presenting such a ridge above the road level that no carriage could cross, except at an angle approximating to a right angle, without the wheels skidding. Such a construction, it was hardly necessary to say, would not be permitted for English tramways. In corroboration of Professor Unwin's reference (page 102) to the

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use frequently made of tramcars in America in ways which would not be dreamed of in this country, he had himself noticed that it was there the practice for any one to hire a tramcar for a picnic or simply for a ride, and to have it decorated with electric lights all over, and to take a party of friends for a high-speed trip out into the country and back again. Such a practice was hardly likely to come into vogue here.

In the electrical details dealt with in the paper and partly displayed in the diagrams, he considered there was just as much room for criticism as there was on the question of fly-wheels and of high-speed compared with slow-speed engines. In Table 4 he enquired what was meant by construction and equipment; did this item apply merely to the construction of the electrical apparatus and to the electrical equipment, or did it apply to the entire construction of the tramway itself? And could any satisfactory explanation be given, why some of the trolley wires had recently come tumbling down in Boston (page 103) and slaughtered two hundred horses? An American witness before a committee of the House of Commons had positively asserted that there had been absolutely no electrical accident with any of the trolley wires in America. When asked what had been the cause of about forty people having been killed at the termination of the Brooklyn line, he had answered that it was not an electrical accident at all; it was simply the breaking of the trolley wires, which was a mechanical accident. With regard to the Boston accident, it would not be satisfactory to receive a similar answer that it was not due to the overhead trolley wires, but was simply due to the snow; and he was sure the author would not desire to meet the enquiry with any such answer.

Mr. CHARLES H. GADSBY noticed that in the construction of the poles (page 48) it was stated that the joint was made by heating the larger tube to a welding heat, slipping it over the smaller tube, and then passing the two between rollers, and that they were found to be thereby welded together solidly. How a hot tube could be welded on a cold one by that method, or how any hot piece of metal could be welded on a cold piece, he could not understand. An important mechanical feature of electric traction he considered was the matter of wheels, which he regretted had not been dealt with more fully in the paper. The wheels for the electric cars in America differed from those used in this country; practically all of them were cast-iron wheels with considerable chill on the tread. An important point in American practice was that these wheels were never keyed upon their axles. In this country experience based on locomotive work had led to keying the wheels on the axles; but American practice had shown that this was unnecessary. The absence of keys was a great advantage where frequent renewal of the wheels was necessary; when properly bored they were quite secure without keys, if put on by about 30 tons hydraulic pressure. Respecting the unsightliness of overhead trolley wires, it was a curious fact that almost all the deputations sent by corporations in this country to the Continent and elsewhere to report upon the overhead system, with the one exception he believed of the Birmingham deputation, had reported on their return that after a few days' familiarity with overhead wires they saw no objection whatever to them from an æsthetical point of view. As to the construction of conduit systems in New York (page 103), there was no difficulty whatever in designing a conduit which would fulfil all the conditions required in this country except one, namely that of finding the money to lay it, inasmuch as a conduit involved an outlay of from £15,000 to £20,000 a mile for roadwork alone.

Mr. CHARLES DAY noticed in page 71 a sort of comparison of electric-traction engines with those of rolling mills; and some particulars of each class were given in Tables 12 and 13, from which the deduction intended to be drawn seemed to be that electric-traction engines were made much heavier than rolling-mill engines. But in Table 13, pertaining to rolling-mill and other continental engines, he certainly found that the dimensions given were much less than those adopted in English practice; and he should have liked a comparison of the American engines with English engines of the same class, not necessarily driving electric-traction stations, but of the same general type: that is, a comparison of American long-stroke

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Corliss engines with similar English engines. From the few data given—only the cylinder diameter, the stroke, and the size of the bearings—a clear idea could not be formed whether these were large or small bearings; all that could be said was that they appeared to be small, much below English practice for rolling-mill engines, and also below that for cotton-mill engines. The total loads upon the bearings were not given, so that the bearing pressures upon them could not be worked out. Similarly in Table 12 referring to the electric-traction engines, the kinds of engines were not stated, and the total loads upon the bearings were not given; only the total weights were given, and the sizes of the bearings. In this incomplete form he thought these two tables were liable to mislead; their intention seemed to be to convey an idea of great extra weight in the electric-traction engines, but he thought they could not be taken as proving this. The best modern Corliss engines for driving cotton mills he believed would be found to be of fully the same total weight as these electric-traction engines. In such electric-traction engines as those to which Table 12 applied, he recognised that the crank-shaft bearings must necessarily be larger than in cotton-mill engines, not for any reason of greater strength, but simply in order to give the necessary bearing area to carry the weight of the larger fly-wheel and also the weight of the generator, the latter forming a big item. In designing engines for cotton mills, it was necessary in deciding the diameter of the crank-shaft to consider not only the stresses on the shaft necks due to the driving of the shaft, but also the dead-weight bearing pressure on the bearings; because if these bearings were kept too small, they invariably occasioned trouble with hot necks. Therefore one of the conditions under which the crank-shaft necks had to be designed was to meet the dead weight they had to carry; and consequently electric-traction engines, which carried much heavier weights than any rope-driving or similar engines, ought to have bigger bearings. In the weights of engines given in Table 12 he should like to know what proportion occurred in the fly-wheel, the crank-shaft, and the generator: in order that it might be seen how far the engines themselves were heavier than engines of the same type built for other purposes.

Mr. Harold Lomas in the absence of the author replied to Mr. Holroyd Smith's enquiries, that the report of two hundred horses having been killed in Boston by exposure and by the falling of trolley wire (page 110) had appeared in an American newspaper; but no information had been received as to the exact amount of trolley wire which came down, nor did he know how severe the storm had been. The temperature he expected had been much below what was ordinarily experienced in this country; and it was possible that the breakage of any trolley wires might have been due to extreme cold. In Table 4 the figures given for cost of construction and equipment (page 110) included poles, trolley wires, insulators, erection, and track construction.

The President invited the Members, in the absence of Mr. Dawson, to pass a hearty vote of thanks to him for the trouble he had taken in preparing this valuable paper. It had elicited an interesting discussion, in which it had been severely handled. Mr. Mark Robinson had advocated high-speed engines, as against low-speed engines with large fly-wheels. Mr. Head had given some valuable information about American tramways worked electrically, and about the special circumstances existing in that country as contrasted with this country. Mr. Beaumont had criticised unfavourably the American electrical tramway practice as compared with the English. Sir Frederick Bramwell had referred to the parliamentary restrictions in this country as limiting and checking private enterprise in tramways, in contrast with the freedom enjoyed in America. Professor Unwin had protested against undue adverse criticism of details, and had given instances of electrically driven tramways in Ottawa and Boston, and had expressed himself satisfied with the American long-stroke engines having heavy fly-wheels, while admitting that short-stroke engines were most convenient. Professor Kennedy had maintained that there was no difficulty in working tramways with high-speed engines just as well as with slow-speed engines. Mr. Sharp had dealt with strains in fly-wheels, and had advocated tangent-spoke fly-wheels of special construction with numerous spokes. Mr. Holroyd Smith had commented on the

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tramway rails and roads in America; Mr. Gadsby on the poles and the tramcar wheels; and Mr. Day on the dimensions of the bearings and shafts in American practice as compared with English practice. To these comments, as well as to those in the previous discussion, the author would send his reply.

Mr. E. Kilburn Scott wrote to ask the author's opinion as to the relative merits of the Eickemeyer and the barrel form of armature winding: whether the consequent pole construction, as in the G.E. 800 motor (page 66), was better or worse than having four separate field coils; and also whether there was any advantage in laminating the field poles. The G.E. 52 motor, which he preferred to the G.E. 800, appeared however to be rated on a different method, and not by the torque exerted at the circumference of a 33-inch wheel. Having recently had an opportunity of examining some of the thirty-three motors which were being built at Wolverhampton for the Halifax tramways, he considered that in general appearance and proportions they were at least equal, and in finish superior, to anything he had yet seen which had been turned out abroad. Until they had been at work some time, any opinion upon their running properties would be premature; but if they gave satisfaction upon the Halifax gradients, they would have passed through as severe a test as a car motor could well be put to in this country.

Mr. Dawson wrote that the object of the paper had been simply to lay before the Institution what had been done in the field of electric traction in other countries, as unfortunately so little had yet been accomplished in this country, and the work which had already been done was comparatively recent only, and therefore no conclusions could be drawn therefrom. Practically both in America and on the Continent of Europe a large number of electric lines had been equipped, and engines of many different classes had been tried; and as the result it had there been found that comparatively slow-speed engines, heavily built and with heavy fly-wheels, were required to give good service. The question as to engines, raised by both

Mr. Crompton (page 78) and Mr. Raworth (page 84), was one on which the greatest authorities disagreed, both in this country and elsewhere; and practice alone would decide the points at issue. As the largest examples of electric traction were found in the United States, it was from experience there gained that the conclusions embodied in the paper had been drawn. Furthermore the most important developments of electric traction in this country had been carried out on the lines of American practice, and had given the greatest satisfaction. If some of the eminent builders of slow-speed engines in this country had taken part in the discussion, it would not have appeared as though the only engines built or used here were of the high-speed kind, which was by no means the case. From some of the criticisms offered respecting the slow-speed engine, it might almost seem as though the high-speed engine alone represented English practice, and that the slow-speed engine was distinctively an American product. On the contrary however some of the most successful traction and lighting stations in this country were driven by slow-speed engines of English build. Two examples of such traction stations were the City and South London, and the Liverpool Overhead. Moreover for the Central London Railway now under construction the most careful consideration and examination of existing examples and promised performance had led to the decision to use slow-speed engines. The 1,500 horse-power high-speed engine for Liverpool, cited by Mr. Mark Robinson (page 93), would not seem large compared with the five compound engines, each of 5,000 horse-power, now being built for the Metropolitan Railway of New York, which would be directly coupled to 3,000 kilo-watt generators; they had 60 inches stroke, with 47-inch high-pressure and 87-inch low-pressure cylinders, and were to run at 75 revolutions per minute with 160 lbs. steam pressure, having fly-wheels weighing 120 tons each. Nothing had been said as to total steam consumption, and he thought high-speed engines would find it difficult to do better than 12 lbs. of steam per I.H.P. per hour during regular running, not during a test, which was the consumption guaranteed in several instances by the Edward P. Allis Co., of Milwaukee.

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It was because this country had been invaded by American engineers and their practice that he had tried to put forward the conclusions arrived at in America, where experience had been acquired and paid for during the last ten years, while this country had only just started upon her career in electric traction; and it was desirable to profit by others' experience, and to improve upon their methods. Other things being equal, English engineers could undoubtedly do as well as foreigners (page 78), if not better; but it was essential that they should first study what had been done elsewhere. Both in America and on the Continent the views of Mr. Crompton, who had done so much for electric lighting, had formerly been held, in regard to the same kind of engine being suitable both for lighting and for traction; but they had since had to be discarded. In electric lighting the superiority of this country had not been questioned; and if we took care to learn first from the experience which had been gained elsewhere, there was no doubt that in a few years we should have as fine electric-traction stations as were to be found anywhere. The following five were the only electric-traction stations he knew of, which were driven by high-speed engines running faster than 200 revolutions per minute:—Balls Bridge (Dublin) first set of machinery; Hartlepool; Liverpool; Bradford; City and Waterloo. On the other hand the following eighteen were or would be driven by slow-speed engines not exceeding 200 revolutions per minute:—Balls Bridge (Dublin) extension; Clontarf (Dublin); Dublin, new; Cork; Bristol; Sheffield; North Staffordshire; South Staffordshire; Dover; Leeds; City and South London; Central London; Middlesbrough; Glasgow; Liverpool Overhead; Coventry; Norwich; Isle of Man. Figures in substantiation of the superior advantages of high-speed engines would have been of much interest and value at the present time, when he not infrequently found that the conditions laid down in what were considered to be standard specifications were regarded by engine builders as too rigorous.

In explanation of the changes which had had to be made in the generating station in Boston (page 81), it should be noted that at the time it was first equipped the design and construction of dynamos were not well understood, and it was considered impracticable to build any but small high-speed generators. Not only in America but also in Europe tramway experience had led to the conclusion that slow-speed engines were the only proper plan for working economically and with good results generally. There might be exceptional cases where first cost was the main consideration, or where the site of the generating station was so confined that there was not room enough for any but high-speed engines. Absence of shocks in engines supplying electric power (page 84) was contrary to the experience of all large electric-traction stations. It might be realized in an engine running at a very high speed with no fly-wheel; but unfortunately such an arrangement would never give satisfaction. Even in the largest stations momentary sudden increase of load was always taking place, and the engines must be able to stand sudden momentary overloading; hence the absolute necessity for a fly-wheel, without which the engines would have to be kept running much underloaded in their regular work, and therefore far from economically.

If properly designed, a large fly-wheel, as pointed out by Professor Unwin (page 104), would not be more dangerous than a small one running with the same rim velocity. In the experience of the Edward P. Allis Co., who had constructed hundreds of engines and the largest fly-wheels, he was informed that not a single fly-wheel accident had occurred with any one of their engines.

As regarded the need of governing engines within a small percentage of uniform speed (page 85), this was absolutely necessary where compound-wound continuous-current dynamos were running in parallel. If the speed of such dynamos varied too greatly from their normal rate, the current through the equalizing bars would become excessive, and it would be difficult to keep the dynamos running properly; besides which there would be a waste of power. If the difference in speed between the machines became too great, one of them might even be reversed. Where polyphase generators were used, it was easy to see the necessity of running as nearly as possible at the normal speed without variation, because

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otherwise there would be a great danger of the dynamos getting out of synchronism. This was so far realized that many builders of polyphase machinery undertook that the maximum variation of the angular velocity during one revolution should never exceed half of one per cent., and in many instances a quarter of one per cent. was the limit assigned. There would be only one way to prove that these views of practical builders were wrong, and that would be by having reliable tests made on the different kinds of engines giving different closeness of regulation, the tests on both engines and dynamos being made by disinterested persons and not by the builders themselves. It was owing to the necessity of having so small a variation in speed, and of yet being able to supply power momentarily, that fly-wheels had to be made so heavy; consequently the engines were subjected to severe shocks, and had to be proportionately much heavier than those built for ordinary electric lighting. Over-compounding, as carried out for the dynamos used for electric lighting (page 86), was nearly always adopted for electric traction, for which most of the compound generators were over-compounded 10 per cent.

There were two reasons for making poles in three lengths of straight pipe, instead of rolling them taper in a single length as recommended by Mr. Chambers (page 87). The first was because it had been found cheaper in practice to make poles in three lengths than to make a single taper length; the second, because where brackets were used a taper pole fixed absolutely the particular height at which the bracket had to be placed, and the bracket could not afterwards be shifted up or down on the pole wherever it might be found more suitable. The taper poles also rendered the cost of manufacture of the brackets more expensive, inasmuch as these had to be made and fitted more carefully than where they were fixed to poles constructed of parallel tubes. These ornamental poles used for electric tramways were not fixed in cast-iron bases, but were sunk six feet in the ground, the hole being filled in round with concrete. Practice had proved that poles made in three lengths, and jointed afterwards when they were being erected, never gave satisfaction for electric tramways. Moreover standard poles made as described in the paper were supplied from America at just over one penny per lb.; and as their weight for standing strains from 500 to 2,000 lbs. varied from 400 to 1,900 lbs., it would be found that American prices were little more than half of English.

The test for the poles, commented upon by Mr. Harris (page 88), was that imposed in England, and was considered satisfactory by the engineers responsible for the acceptance of the poles.

In connection with Mr. Mordey's remarks (page 88), he would suggest that it was desirable not to under-estimate our American competitors, who in the particular subject of electric traction had had more experience than anyone else; from their failures and successes we might try to learn how to do better ourselves.

Upon the subject of fly-wheels it was clear that Mr. Robinson's views (page 91) did not agree with those of Mr. Raworth. If the fly-wheel on an engine used for electric traction was required to be heavier than on the same engine used for electric lighting, it seemed to be implied that in the former case the engine was subjected to greater shocks, and that therefore its frame and working parts must be made stronger than for electric lighting. But it was a mistake to speak of high-speed engines as though these were the more prevalent in this country, and of slow-speed as though they were a foreign product. On the contrary the high-speed engine was of relatively recent origin here, and could not yet compare in extent of adoption with the large slow-speed engines turned out by many eminent builders. Alongside the one high-speed electric-traction engine of 1,500 I.H.P. ordered for the Liverpool tramways (page 93) should be placed the more interesting example of the Liverpool Overhead Electric Railway, which had proved such a great success. This was probably the largest example of electric traction as yet to be found here, and it had been working now for several years. It comprised some remarkably fine engines, all of which were slow-speed; and in all the extensions which had subsequently been made the new engines had been of the same kind.

The means of rapid and comfortable transit, Mr. Head was right in representing (page 95), were hardly yet rated at their proper value in this country; and the great success attending

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electric traction in America went far to indicate that here also there was a vast field for its successful adoption.

The title of the paper might indeed fairly have been that suggested by Mr. Beaumont (page 99). For was not America the only country which had as yet had any large experience in electric traction? What was there hitherto in England or in the rest of Europe to show in comparison? Probably in a few years no one would think of saying that the paucity of electric tramways in this country was owing to the English people knowing better. Already the large towns he had previously enumerated (page 116) were adopting electric traction upon an extensive scale, and many others had decided to follow suit. For transforming the crowded streets of English cities from their present condition of omnibus yards, English tramway engineers had long ago got over the fallacy that a two-horse tramcar could be successfully driven by a 2-horse-power motor (page 101); they fully recognised that small motors were useless, and that great reserves of power were required. Steam locomotives with their history of nearly a century (page 101) could hardly be brought with fairness into comparison with electric traction, which as yet had a practical history of only about ten years.

Notwithstanding the way in which, as pointed out by Sir Frederick Bramwell (page 101), English enterprise in tramways was checked by the tramways act of 1870, electric traction was already advancing here by leaps and bounds.

In respect to the ugliness of the trolley wires, noticed by Professor Unwin in the narrow streets of Boston (page 103), American construction had certainly been much improved upon in this country. What was known as the Dickinson side trolley, which had been adopted by himself on a large number of lines, had done much to make the overhead wires not half so unsightly in English towns as they were in many American cities.

The accident stated to have been caused in Boston by the trolley wires (pages 103 and 110) had happened during a blizzard, when for nearly a week no trains could get in or out of Boston, and snow lay so deep that for some days people were practically confined to their houses. The trolley wires had probably fallen, just as all the telegraph and telephone wires had fallen, owing to the violence of the blizzard, which in this country was fortunately almost an unknown visitant.

The dimensions of the rolling-mill engines in page 71 were given only to show that engines for electric traction resembled in their weight and design rolling-mill engines (page 111) much more than they resembled electric-light engines. As to the dimensions of slow-speed long-stroke engines used for electric traction (page 112), the following conditions had been found to produce good results, and were generally adopted in American tramway practice. The dimensions of the bearings, piston rods, crank pins, front frame, and cross-head pin, were always designed as if they were for an engine intended to work under a constant load and having cylinders from 2 to 4 inches larger in diameter than those of the actual engine about to be used. For the fly-wheel capacity a simple rule was to take the total indicated horse-power at which the engine was rated, for speeds ranging from 140 down to 75 revolutions per minute, and to allow from 60 to 100 lbs. weight in the fly-wheel per I.H.P. For the fly-wheel shaft it was always preferable not to have more than two bearings; and from the weight of the fly-wheel and armature was obtained the size of the shaft, and thence the diameter of the bearings. The length of the bearings was got from the consideration that the pressure on the projected area of the bearing, that is the diameter multiplied by the length, was never under any circumstances to exceed 200 lbs. per square inch, and should generally be somewhere about 150 lbs. The piston speed should not be higher than 750 feet per minute. The diameter of the fly-wheel was determined from the highest rim-speed allowed. When the wheel was properly designed, and constructed of the best cast-iron or semi-steel, the rim speed was about a mile a minute; and under such conditions it was found that the fly-wheel had a co-efficient of safety of from 10 to 15. The semi-steel used for fly-wheels built by the Edward P. Allis Co. had a tensile strength up to 33,000 lbs. or nearly 15 tons per square inch. Upon the crank pin and the cross-head pin the pressure per square inch of

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projected area should never exceed 1,400 lbs., and it was better to keep it down to 1,000 lbs. In order to afford some idea of typical engines used for electric traction, Table 16 gave the leading dimensions and weights of four Corliss engines recently erected for this work.

TABLE 16.—*Dimensions and Weights of four Compound Condensing Corliss Engines recently erected.*

H = Horizontal with cranks at right angles.
T = horizontal Tandem with single crank.
V = Vertical with cranks at right angles.

Description of engine		H	T	V	H
Revolutions per minute		75	80	100	140
Diameter of High-pressure cyl.	inches	32	28	23	18
,, ,, Low-pressure cyl.	inches	62	52	46	23
Length of stroke	inches	60	48	48	42
Fly-wheel, diameter	feet	24	20	18	16
,, weight	lbs. tons	150,000 67·0	120,000 53·6	70,000 31·2	53,000 23·7
Shaft diameter	inches	26	23	21	20
Journals, diameter and length	inches	22×42	20×36	18×36	16×28
Crank pins, ,, ,, ,,	inches	11×11	10×10	6½×6½	7×7
Cross-head pins, ,, ,,	inches	10×10	10×10	6½×6½	7×7
Rated power of dynamos	kilo-watts	1,500	800	800	300
,, ,, ,, engine . . .	I.H.P.	2,100	1,200	1,200	500
Weight of engine, total . . .	lbs. tons	537,000 239·7	308,000 137·5	300,000 133·9	203,000 90·6

The general conclusion in regard to engines suitable for electric traction might be summed up by saying that, owing to the fluctuation in the load, a certain amount of energy must be stored up in the fly-wheel to be given out whenever required. Naturally the higher the speed of the engine, the smaller would be the weight of fly-wheel required. Owing to the small variation allowable in speed if compound-wound dynamos were to run economically, the weight of the fly-wheel had to be such that it would give out momentarily the extra power required, without falling below the number of revolutions per minute corresponding with the maximum variation allowed in speed, which was about 2 per cent. total, that is 1 per cent. on either side of the mean.

The adoption of slow-speed or of high-speed engines was altogether a matter of economy. The original cost of a slow-speed engine was naturally rather higher than that of a high-speed for doing the same work; but the mechanical efficiency of a slow-speed engine was greater than that of a high-speed, and its steam consumption was less. Furthermore the depreciation of a slow-speed engine would be less than of a high-speed. Moreover, should anything go wrong in a slow-speed engine, it might be discovered in time to stop the engine before any material damage was done; whereas in a high-speed engine this was less likely, and the engine might go to pieces before it was discovered that anything was wrong.

DIAGRAMS TO FACILITATE THE DESIGN OF RIVETED JOINTS FOR BOILER WORK.

By Professor W. E. DALBY, of London.

Having had occasion to study somewhat closely the Reports of the Institution Research Committee on Riveted Joints,* the author found so much help from the graphical expression of the equations in a certain way, that he thought the diagrams shown in Plates 15 to 17 might be of use and interest to other Members of the Institution.

Unless otherwise stated, the tearing resistance of the plate between rivet-holes will be taken at 30 tons per square inch; the shearing strength of the rivets at 22 tons per square inch; and their bearing resistance at 40 tons per square inch.

The conditions to be satisfied for a single-riveted lap joint of maximum strength are expressed by the relations:—

$$\frac{\pi}{4} d^2 s = (p - d)\, t f = d t b \quad . \quad . \quad . \quad (1)\dagger$$

$$\left.\begin{array}{l} d = \text{rivet diameter after riveting} \\ p = \text{pitch} \\ t = \text{thickness of plate} \end{array}\right\} \text{in inches.}$$

$$\left.\begin{array}{l} f = \text{ultimate tearing strength of plate} \\ s = \text{ultimate shearing strength of rivet} \\ b = \text{ultimate bearing resistance of rivet in plate} \end{array}\right\} \text{in tons per square inch.}$$

One of the three variables d, p, t, being given, the other two may be found. In practice two of them are usually given, namely the rivet diameter and the thickness of plate, between which the relatio is determined by practical considerations and not by the conditions set forth above. Substituting these values in the first two of the above relations, and neglecting the third, the pitch may be found for securing equality of tearing and shearing resistance.

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* See Proceedings 1881, pages 205, 293, 301, 712, and 720; 1882, page 138; 1885, pages 198 and 236; 1888, page 538.

† See "Elements of Machine Design," by W. C. Unwin, twelfth edition, vol. 1, page 107.

Given the rivet diameter and plate thickness, to find the pitch so that the tearing and shearing resistances may be equal.

$f = 30$ tons per square inch ; $s = 22$ tons per square inch.

Considering the case of a 1-inch rivet in a $\frac{1}{2}$-inch plate, the pitch p would usually be found from the equation

$$\frac{\pi}{4} \times 1^2 \times 22 = (p - 1) \times 0 \cdot 5 \times 30 \quad . \quad . \quad (2)$$

To find it graphically, take a horizontal base line XX, Fig. 1, Plate 15, and choosing a point O in it, set out the rivet diameter OR to the left of O : calculate the shearing resistance of the rivet ; in this case $0 \cdot 785 \times 22 = 17 \cdot 28$ tons. Erect a perpendicular RS at R, making its height proportional to the shearing resistance of the rivet, that is 17·28 tons. Set out to the right of O a distance OT representing some assumed distance between the rivet-holes ; this distance is equal to $(p-d)$, supposing p and d to be known. Calculate the tearing resistance of the plate corresponding with this distance, and set it up vertically at TB to the same scale as that used to represent the shearing resistance of the rivet. In the present example it is convenient to assume OT = 2 inches, because the tearing area of 2 inches of $\frac{1}{2}$-inch plate is 1 square inch, and its tearing resistance is 30 tons. Then TB represents 30 tons. Join OB. For any distance OK between the rivet-holes the corresponding tearing resistance is represented by KK_1. Draw a horizontal line through S, cutting OB in P. Then $SP = (p - d + d)$ represents the pitch to fulfil the condition that the shearing resistance of the rivet shall be equal to the tearing resistance of the plate. SP measures 2·15 inches, and is the same value of p which would be found by solving equation (2).

General solution of the problem.—The form of the equation for the shearing strength of the rivet, namely shearing resistance $= 22 \frac{\pi}{4} d^2$, shows that, for any rivet-diameter set out horizontally to the left of O along OX, the ends of the successive ordinates representing the shearing resistance lie on a parabolic curve, whose axis OY is at right angles to XX, and whose vertex is at O.

It follows therefore that, having given the shearing resistance, such as RS, Fig. 1, Plate 15, corresponding with one rivet-diameter OR, it is only necessary to draw a parabolic curve through S, having its vertex at O, in order to represent graphically the shearing strength of a rivet of any diameter. Such a curve OQ is drawn in Fig. 2; it extends so far to the left that the shearing resistance of any rivet up to $1\frac{1}{4}$ inch diameter may be scaled off.

The form of the equation for the tearing resistance of the plate—namely tearing resistance $= (p-d)\,t\,f = x\,t\,f$, where x is put for the distance $(p-d)$ between the rivet-holes—shows that for different thicknesses of plate the graphical representation of the equation is a family of oblique straight lines all radiating from O. The quickest way to draw these lines is to calculate the tearing resistance for any assumed value of x and t, such as TB, Figs. 1 and 2, Plate 15, and then to divide the vertical line TB into a scale on which TB represents $\frac{1}{2}$ inch. In Fig. 2 the family of radiating lines is shown for plate thicknesses increasing by 1-16th inch from 0 to 1 inch.

The pitch for equality of tearing and shearing may be found from Fig. 2 for any given diameter of rivet and thickness of plate. For example, to find the pitch for $\frac{7}{8}$-inch rivets in a $\frac{1}{2}$-inch plate:—at $\frac{7}{8}$-inch on the rivet-diameter scale erect a perpendicular RS cutting the parabola in S; draw a horizontal line through S, cutting the family of radiating lines. Then SP_1, SP_2, SP_3, &c., each represent the proper pitch for the corresponding thickness of plate. For a $\frac{1}{2}$-inch plate the pitch SP_1 measures $1\frac{3}{4}$ inch.

For double-riveted joints it is only necessary to draw a parabola OQ_1, Fig. 2, whose ordinates are double the corresponding ordinates of the parabola OQ, since the shearing resistance is doubled, whilst the tearing resistance is the same for any given pitch. The pitch for $\frac{7}{8}$-inch rivets double-riveted is found by drawing the ordinate RD to cut OQ_1 in D, and drawing a horizontal line through D to cut the family of radiating lines. Then DP_1, DP_2, DP_3, &c., each represent the proper pitch for the corresponding thickness of plate. For a $\frac{1}{2}$-inch plate the pitch DP_1 measures 2·63 inches. A third parabola may be added for treble riveting, and so on.

Graphical representation of Bearing Resistance.—If the horizontal scale representing the distance x or $(p-d)$ between the holes in Fig. 1, Plate 15, be considered to represent the rivet diameter as well, the bearing resistance will be represented by the ordinates to a family of radiating straight lines, Fig. 2, for different thicknesses of plate. This is shown by the form of the equation (1) for the bearing resistance b. Considering the case of a 1-inch rivet in a $\frac{1}{2}$-inch plate, if b be taken at 40 tons per square inch, the total bearing resistance is 20 tons. This is represented by the ordinate 1 L in Fig. 1. If $x\,f = d\,f$, that is if $x=d$, the ordinate 1 P_1 will represent the bearing resistance of the 1-inch rivet as well as the tearing resistance of 1 inch of the $\frac{1}{2}$-inch plate.

The ordinates to the line OB may be made to represent the bearing resistances of rivets of any diameter in a $\frac{1}{2}$-inch plate by setting out the rivet diameter to a different scale. In Fig. 1 draw a horizontal line through L, cutting OB in M; drop a perpendicular MM_1 from M to the base line XX. If the rivet diameters be set out to such a scale that OM_1 represents 1 inch, then an ordinate from the scale for any chosen rivet-diameter, cutting a radiating line corresponding with any given plate-thickness, will represent the bearing resistance of the rivets in that plate. The new scale may be obtained directly from the relation $x\,t\,f = d\,t\,b$, from which $d = \frac{f}{b} \times x = \frac{3}{4}\,x$, if $f = 30$ and $b = 40$ tons per square inch; that is, when $x = 1$ inch, d must represent $\frac{3}{4}$ inch. Generally the horizontal length on the paper representing 1 inch must be multiplied by $\frac{b}{f}$ to find the length representing 1 inch on such a scale that the bearing pressure shall be given by the ordinates to the same family of radiating lines from which the tearing resistance and pitch are obtained.

Equality of Shearing and Bearing Areas, having given the diameter of rivet.—The plate thickness could be obtained in no simpler manner than by solving the equation $\frac{\pi}{4} d^2 s = d t b$. The graphical solution is given as a step to another problem. Set out the rivet diameter to the left of O, and draw the parabola OQ as before, Fig. 3, Plate 16. Set out the rivet diameter also to the right of O, but to such a scale that the family of radiating lines representing the tearing resistance of the plate may represent also the bearing resistance of the rivets. With the strengths assumed above, the scale will be $\frac{4}{5}$ inch = 1 inch. For any rivet-diameter OR the shearing resistance is represented by RS. Draw a horizontal line through S to meet in P a vertical from the corresponding rivet-diameter 1 inch on the scale to the right of O. The locus of all such points as P is a parabola, Fig. 3, of which OY is the axis and O the vertex. P marks the point of intersection of the horizontal SP with one of the family of radiating lines OP representing the tearing strength of the plate. Each particular plate-thickness is found by referring the line to a vertical scale TZ of plate thicknesses, constructed by the same method as the plate-thickness scale in Fig. 2. It is not necessary to draw the family of radiating lines, and this has not been done in Fig. 3, where the scale shown is divided decimally, instead of into sixteenths as in Fig. 2. The graphical solution of the problem to design joints of maximum strength, assuming a shearing and a bearing resistance for the rivet steel and an ultimate tenacity for the plates between the holes, may now be easily performed. Summarizing the foregoing considerations, the method of drawing the diagram is as follows.

1. Calculate the shearing resistance of a rivet of any diameter preferably the largest that is to be shown on the diagram. Set this up vertically at the corresponding diameter to the left of O, obtaining a point such as Q in Fig. 3, Plate 16.

2. Through this point Q draw a semi-parabola having its vertex at O.

3. Calculate the bearing resistance of a rivet of any diameter. Set out to the right of O a scale such that 1 inch = $\frac{b}{f}$ inches,

supposing the other horizontal scale to the left of O to be full size. From a point T on this right-hand scale, representing the chosen rivet-diameter, erect a vertical line to Z representing the calculated bearing resistance.

4. Through this point Z draw a semi-parabola having its vertex at O.

5. Calculate the tearing resistance of a strip of plate of any width and any thickness. Set out the width of the strip to the right of O full size, say OT, and the tearing resistance vertically, obtaining a point such as B in Fig. 3.

6. Divide the vertical line through B into a scale of thicknesses, on which TB represents the thickness of plate used in the calculation.

The diagram is now ready for use. Fig. 3, Plate 16, has been drawn for the values—

f = tearing resistance = 30 tons per square inch.
s = shearing resistance = 22 „ „ „
b = bearing resistance = 40 „ „ „

Example 1.—To find the proper pitch and plate thickness for a single row of rivets 1 inch diameter, so that the joint may be of maximum strength. At 1 inch to the left of O erect a perpendicular, cutting the left-hand parabola in S, Fig. 3, Plate 16. Through S draw a horizontal line, cutting the right-hand parabola in P. Join OP, and produce the line to cut the plate scale in N. The pitch S P measures 2·34 inches; the plate thickness TN is 0·44 inch.

Example 2.—To find the proper rivet diameter and pitch for a plate 0·3 inch thick, so that the joint may be of maximum strength. Join 0·3 on the plate scale TZ to O, Fig. 3, cutting the right-hand parabola in P_1. Through P_1 draw a horizontal line, cutting the left-hand parabola in S_1. From S_1 drop a perpendicular to cut the rivet scale in R_1. From the diagram the pitch S_1 P_1 measures 1·63 inch; the rivet diameter O R_1 is about 0·7 inch. The efficiency of every joint designed from the diagram in this way is of course the same, being the greatest possible for the strength of the material used. For single-riveting the efficiency is 57 per cent. in round numbers.

The dotted curves in Fig. 3 show the corresponding parabolas OQ_1 and OP_3P_2 for double-riveting. The shearing and bearing areas are doubled, the tearing area remaining the same for the same pitch. It follows that the rivet-diameter scale to the right of O is now doubled, though it is not necessary to show it in either case in this particular diagram, having once drawn the curves. Solving the two foregoing problems for double-riveting, $D_2P_2 = 3\cdot67$ inches (approximately) is the longitudinal pitch for 1-inch rivets; the plate thickness is of course the same, namely $0\cdot44$ inch. For double-riveting in a $0\cdot3$-inch plate the pitch is represented by D_3P_3, which measures $2\cdot57$ inches; the rivet diameter is $O\,R_1 = 0\cdot7$ inch, the same as for single-riveting. The efficiency of the double-riveted joints obtained from this diagram is 73 per cent. The diagonal pitch may be found from the formula :—$\frac{2}{3}\,p + \frac{d}{3}$, where p is the straight pitch and d the diameter of rivet hole (Proceedings 1885, page 251).

If the rivet scales be added to the diagram, Fig. 2, Plate 15, the bearing resistance of the rivet may be read off at the same time that the pitch is found. Excess or defect of bearing resistance is then seen at a glance. Thus in Fig. 2 a $\frac{3}{4}$-inch rivet in a $\frac{1}{2}$-inch plate has an excess of bearing resistance represented by $M_1\,M_2$ or $5\cdot7$ tons. A $\frac{3}{4}$-inch rivet in a $\frac{1}{4}$-inch plate has a defect of bearing resistance represented by $M_2\,M_3$ or approximately 2 tons.

Single and Double-Riveted Butt-Joints.—The rivets being in double shear, full advantage cannot be taken of their shearing resistance. In his Report to the Institution (1885, page 257) Professor Kennedy has shown that, by increasing the bearing pressure to 45 tons per square inch, the rivet may probably be caused to shear at about 16 tons per square inch. Hence in either Fig. 2 or 3 a parabola drawn to the left of O for $s = 32$ tons per square inch, to allow for the double shear, could be used for the design of single-riveted butt-joints. In double-riveted butt-joints there are two rivets to be considered, each in double shear; the parabola would therefore be drawn for $s = 64$ tons per square inch. Such additions to the diagrams however are unnecessary, because the pitch has been shown by the experiments to be about $4\cdot1 \times d$ for double-riveted butt-joints (1885, page 257).

Diagram for finding the pitch to secure equality of shearing and tearing resistances, for any given strength of rivet and any given tenacity of plate.—For practical use the diagram shown in Fig. 4, Plate 17, is perhaps the most convenient. Several plate-scales and shearing parabolas are here drawn for different tenacities and shearing strengths. The distance apart of the plate scales is so arranged that corresponding divisions on all of them lie in a horizontal line, and this diagram can be used to find the pitch. The following general problem can now be solved :—In a single-riveted lap joint to find the pitch that will give equal tearing and shearing resistance for a $\frac{3}{4}$-inch rivet in a $\frac{1}{2}$-inch plate, the ultimate shearing strength of the rivet being assumed at 24 tons per square inch, and the ultimate tenacity of the metal between the holes at 34 tons per square inch. Draw a vertical from $\frac{3}{4}$-inch diameter to intersect the 24-ton parabola in S. Join $\frac{1}{2}$ inch thickness on the 34-ton tenacity scale to O. Draw a horizontal line through S, cutting this radiating line in P; then S P is the required pitch, and measures $1\frac{3}{8}$ inch. For the same conditions in a double-riveted lap joint, S_1 P_1 represents the pitch, and measures 2 inches. This diagram enables joints to be designed quickly, and at the same time affords facility for taking advantage of the increased tenacity of steel plates between the rivet holes, as shown in the Reports of the Riveting Committee, because the appropriate tenacity can be readily selected from the various scales.

MEMOIRS.

STEPHEN ALLEY, whose father was a Dublin medical man, was born on 22nd February 1840 at Blessington, County Kildare, Ireland. Having a strong desire to become an engineer, he commenced his apprenticeship at the age of fourteen with Messrs. Forrest and Barr in Glasgow, and served the greater part of his time with Messrs. A. and J. Inglis. On the completion of his apprenticeship he spent some time with Mr. Edmund Hunt, patent agent in that city. Subsequently he had the management of the tool department in the Hyde Park Works of Messrs. Neilson Brothers. About 1870 he entered into a five years' partnership with Mr. John H. Carruther, who eventually became his brother-in-law, as consulting engineers. During this period he laid out and erected the Clutha Engineering Works for Messrs. P. and W. Maclellan, in the south-western suburbs of Glasgow; and designed the engine which still drives the works of Messrs. Charles Connell and Co., shipbuilders, at Whiteinch. About 1875 he entered into partnership with Mr. John A. MacLellan, and established the firm of Alley and MacLellan, who started their factory under the name of the Sentinel Works in London Road. Here he invented several ingenious machines for facilitating the economic manufacture of special articles. As these works were soon found too small and did not afford scope enough for extension, a new factory was started at Polmadie on the south side of Glasgow, on a site having direct connection with the Caledonian Railway. Here in 1882–3 the manufacture of Mr. George Westinghouse's high-speed engine was undertaken, of which a great number have since been made and are now running in all parts of the world. About the same time the works were extended to include the building of light-draught steamers, many of which were constructed for the navigation of the Nile and of rivers in India and elsewhere. For these the firm also built engines to drive them. They likewise brought out a feed-water filter, an ingenious steam-steering gear, and other valuable engineering devices, which met with appreciation. The works furnish many evidences of Mr. Alley's original inventive ability and clever scheming for economising work and power. Some years ago he joined in establishing the works of the British Hydraulic Foundry at Whiteinch, of which he and his partner became directors. At these works were manufactured the whole of the segments required for the Blackwall Tunnel, London, the largest tunnel yet constructed on the shield and segment method, 27 feet diameter and 6,200 feet long; they amounted to upwards of 20,000 tons. At the same works were also made practically the whole of the segments required by the Glasgow Central Railway; as well as those for one of the Mound tunnels, Edinburgh, constructed by the North British Railway in connection with the widening of the Waverley Station; and likewise 120,000 segments, weighing about 20,000 tons, for the Glasgow District Subway. Each of the moulding machines was capable of turning out one segment every 4½ minutes throughout the whole working day of 9½ hours. Having many years ago joined the board of the Steel Company of Scotland, he was the only engineering director thereon since the death of the managing director, Mr. Henry Dübs. He became a Member of this Institution in 1877, and at the Glasgow Meeting in 1879 contributed a paper on the maintenance of constant pressure in water service pipes; and for the Glasgow Meeting in 1895 he acted as chairman of one of the executive sub-committees. He took a prominent part in the Glasgow International Exhibition in 1888, and for the contemplated exhibition in 1901 was chosen as chairman of the machinery section. His death took place on 23rd March 1898 at the age of fifty-eight, as the result of pneumonia consequent upon taking a chill.

Sir Henry Bessemer was born on 19th January 1813 in the hamlet of Charlton, near Hitchin. Whilst still a youth at home he was always constructing model machines, including in 1830 what is believed to be the first screw-propeller, which differed from modern screws in having an entire thread; the boat to which it was applied was propelled across a pond by means of a weight suspended from a string passing over the mast-head and wound round the screw shaft. On 4th March 1830 his father removed to London, where he made a great reputation as a type founder in partnership with Mr. Henry Caslon. In 1832 he devised a method of impressing stamps upon deeds, which was practically proof against forgery; although it was eagerly adopted promptly by the inland revenue department, the inventor was practically ignored; and it was not till after forty-six years' delay that he received the tardy honour of knighthood on 26th June 1879. In 1833 he exhibited a plaster model of a church at the Academy then held in Somerset House. Among his early inventions was one for the production of the so-called Utrecht or stamped velvet, for which he made both the designs and the embossing stamps; one of the designs was subsequently selected for furnishing one or more of the state rooms in Windsor Castle. About 1838–40 he invented machinery for the manufacture of bronze powder, which was carried on as a successful and lucrative business for more than twenty years. Other inventions came in about the following order. A means of consolidating plumbago dust into a solid block for the manufacture of pencil leads, which is still in regular use. Type-casting machinery, 8th March 1838, in which he introduced a force pump for driving the metal into the mould, is believed to be the first that was devised for the purpose, and in conjunction with type-composing machinery which he subsequently invented is now used in a modified form for the linotype process. In the manufacture of glass, 30th July 1846, he made what is believed to be the first trial of liquid rolling through rolls kept cool by water circulation, whereby a strip of plate-glass was rolled about 4 feet wide and 70 feet long, which however, spreading over the floor of the building, cracked all to pieces in cooling before it could be further dealt with; a cutter was afterwards added for cutting it off in lengths convenient for annealing as it left the rolls. At the first meeting of this Institution at which the real work of the Institution was commenced by the reading and discussion of papers—held on Wednesday 28th April 1847 at the former Queen's Hotel, which at that time adjoined the original terminus of the London and North Western Railway in Curzon Street, Birmingham—a paper was contributed by "Mr. Henry Bessemer, manufacturer, London," upon a mode of doing away with the necessity for coning the tires of railway wheels, by dividing the axle into two half lengths, held together rigidly by a long central coupling with concentric grooves, so that each wheel with its own half of the axle could revolve independently of the other; and he left a model of the plan, which was preserved until the removal of the Institution office to London in 1877. In 1849 he devised what is presumed to be the first centrifugal pump, afterwards improved by both Appold and Gwynne, and also applied it for ship propulsion; a drawing of it was given in the Institution Proceedings in connection with a paper on centrifugal pumps in 1852 (Figs. 9 and 10, Plate 69). In 1849 he also invented machinery for making briquettes of coal dust, for enabling this waste material to be profitably utilised. His invention of continuous brakes for railway carriages, 9th December 1853, using water instead of air, was the fore-runner of the Westinghouse and other continuous brakes now in use. His quick-firing or repeating gun, 25th August 1854, in which the explosion of the powder ejected the cartridge and reloaded the gun, presented the germ of the Maxim gun. For firing elongated shot from smooth-bore guns he made the shot to revolve in its flight by the passage of the powder gases and air through curved holes in its body; and shots were successfully fired in this way in trials made at Vincennes by direction of the Emperor of France, by whom he was offered the Grand Cross of the Legion of Honour, if he could obtain permission to wear it, which was refused to him. In 1861 he gave a paper at the summer meeting of the Institution in Sheffield on the manufacture of cast steel and its application to constructive purposes, describing the apparatus then working there for the manufacture of Bessemer steel at Messrs. John Brown and Co.'s Atlas Steel Works. In illustration of the paper he exhibited an 18-pounder gun made of the Bessemer steel cast in a single ingot of the required size and subsequently hammered, with a variety of specimens of the metal, broken to show the quality of the fracture; also some piston rods, a boiler-plate flanged for a locomotive fire-box, a plate bulged in a die without cracking or tearing, a plate of thin metal punched with a number of small holes very close together, and a tube of the metal which had been crushed flat without the surface cracking. This was only five years after the first announcement of the Bessemer process in his paper read in 1856 at the Cheltenham meeting of the British Association, of which no record beyond the bare title is to be found in the report of the association for that year. An appreciation of the vast extent and importance of this invention was included in the presidential address at the Birmingham jubilee meeting of the Institution in 1897 (pages 265–6). From abroad he received many distinctions, in recognition of the immense services he had thereby rendered to mankind; and in America some seven towns and cities have honoured themselves by adopting his name. He became a Member of this Institution in 1861, and was a Member of Council from 1871 to 1878. In 1871–3 he was President of the Iron and Steel Institute; in 1877 he became a Member of the Institution of Civil Engineers; and in 1879 a Fellow of the Royal Society. His death took place at his residence at Denmark Hill, London, on 15th March 1898, at the age of eighty-five.

Sir **BENJAMIN ALFRED DOBSON**, son of Mr. Arthur Dobson of Belfast, was born on 27th October 1847 at Douglas, Isle of Man. After being educated at the Grammar School, Carlisle, and the Collegiate Institute, Belfast, he studied as a mechanical engineer, and eventually entered the Kay Street Works of Messrs. Dobson and Barlow in Bolton, then conducted by his uncle. Mr. Benjamin Dobson. On the retirement of the latter in 1871, he became a partner in the business with Mr. T. H. Rushton. He went through the several departments of the establishment, and thus acquired a practical knowledge of machine-making, both in the preparatory stages and in finishing. In 1890 he went to Constantinople, in order to superintend personally the work at the Yedi Koulé Cotton Spinning Mills, for which the machinery had been supplied by his firm. In connection with his business he also travelled on the Continent, in the United States and Canada, Egypt, India, and Japan. He was the author of works on "cotton carding and card clothing," on "humidity in cotton spinning," and on "some difficulties in cotton spinning"; and of "a visit to cotton land," in which he recorded his observations during his travels in the Southern States of America. In 1893 he read a paper to this Institution upon the artificial lighting of workshops, and in 1894 another upon electric welding; in both of these he described what had been carried out at his own works, and gave the frankest information as to the nature of the many difficulties encountered and the practical means whereby the successful results realised had been arrived at. Without professing to be an electrician, both papers showed that he had come conspicuously to the front among mechanical engineers in the way of utilising electrical science to the utmost. He became a Member of the Institution in 1872, and was a Member of Council from 1885 to 1891, and again from 1894 till the time of his death, which took place on 4th March 1898, in the fifty-first year of his age, from an attack of pneumonia. In this year he was Mayor of Bolton for the fourth time, having been knighted in the previous year on the occasion of the diamond jubilee celebration of the Queen's reign. As chairman of the Bolton engineering employers' association, he was selected by the federation of engineering employers to represent them at the conferences which resulted in the termination of the long strike in the engineering works throughout the country. Under his guidance as chairman of the technical instruction committee, the old Mechanics' Institute in Bolton was transformed into a well equipped Technical School. He was also President of the Bolton Chamber of Commerce. In 1878 the order of Chevalier of the Legion of Honour was conferred upon him by the French government, in recognition of his great services to French industry.

George Edward Hall was born at Salford on 29th August 1843. After serving his time from 1854 to 1863 at the works of Messrs. Higgins and Sons, machinists, Salford, he was employed at the works of Messrs. Sharp, Stewart and Co., from 1863 to 1865 as turner and screw-cutter. He then became leading hand at Messrs. Higgins and Sons until 1869, when he entered the service of the Salford Corporation as an inspector in the lighting and scavenging department; and in 1876 he succeeded to the post of superintendent of the lighting department, and was also appointed to superintend the mechanical and wheelwrights' work. To these duties was added in 1880 the superintendence of the scavenging department. In 1892 on the amalgamation of the three districts of the borough he was appointed chief superintendent of the lighting and scavenging of the whole. In both departments he introduced various improvements, and as one of the first to employ destructors for disposing of refuse by burning he devoted much care and attention to improving their efficiency. His death took place on 18th March 1898 at the age of fifty-four. He became a Member of this Institution in 1892.

JOHN SATCHELL HOPKINS was born at Wolverhampton in December 1825, whence his father, Mr. John Head Hopkins, removed a few years afterwards to Birmingham, where with his son he established in 1850 the Tin-Plate Works in Granville Street still known by the name of J. H. Hopkins and Sons (Proceedings 1897, pages 388–90). Following up the employment of steam machinery for stamping, spinning, and burnishing, he introduced at these works twenty-five years ago pressure-plate presses, and machines for spinning, forming, trimming, wiring, &c., which were the first machines of the kind erected and used in this country, and except in some minor points indicated by continued experience have never yet been improved upon. Besides largely extending the manufactory in conjunction with his brother, he occupied an influential position in connection with numerous local concerns, of which he was the chairman of several. His death took place suddenly on 11th February 1898, in the seventy-third year of his age, from failure of the heart's action. He became a Member of this Institution in 1866.

THOMAS SIBLEY WHITTEM was born at Coventry on 15th May 1835, his father being a colliery owner and at one time mayor of that city. Having received his early education in Coventry and Glasgow, he entered in 1852 the engineering works of Messrs. Thornewill and Warham at Burton-on-Trent as an articled pupil, and subsequently served there as an improver. The experience so gained in the construction and erection of all kinds of colliery machinery for winding, ventilation, pumping, and haulage, enabled him on leaving Burton to join his father in the management of the Wyken Colliery near Coventry, of which he greatly improved the equipment, and devised many useful appliances in connection with the machinery. On his father's death in 1884 he became the managing partner, and displayed his enterprise and ability in sinking a fresh pair of pit shafts through the heavily watered strata of the new red sandstone to reach the principal coal seams of the Warwickshire district in these he then opened out workings. He was one of the first to apply the modern enclosed quick-revolution engine for colliery ventilation; and he successfully erected an underground pump worked by electric power for lifting the water out of the workings at a considerable distance from the pit bottom against a head of 750 feet. His death took place on 22nd April 1898 in the sixty-third year of his age. He became a Member of this Institution in 1869.

Robert Wilson, eldest son of Robert Wilson of Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft (Proceedings 1883, page 29), was born at Low Moor, Yorkshire, on 14th December 1851. He was educated at Edinburgh University, and between terms received a considerable amount of practical training in the engineering departments and drawing office of the Bridgewater Foundry, in which his father had then become the managing partner. In 1873 he went to India, where during the two following years he acted as the representative of his father's firm, for erecting machinery and opening up business connections in various parts of the country. He also travelled in Burmah, China, Japan, and America. In 1877 he became a partner in the business; and in 1881, when it was merged in a limited company, he was made the managing director. Being interested in the Koepe plan of winding from deep collieries by means of an endless rope, he read a paper on this subject in 1883 to the Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers. Having in 1884 established himself as a consulting engineer in Westminster, he paid several visits to America, Spain, and Majorca; and subsequently became one of the consulting engineers to the Antimano Railway in Venezuela, the Thames Valley and Rotorua Railway in New Zealand, the Auckland and Melbourne tramways, the Wellington and Manawatu Railway, the New Zealand Government Railways, and the Westport Harbour Board. His first visit to the antipodes was in 1886, with a view to the formation of the New Zealand Midland Railway. With the object of substituting an incline for a summit tunnel on this line, he investigated the cost of working the Hartz Mountain Railway, upon which he read a paper to the Institution of Civil Engineers in January 1889 (vol. xcvi, page 131). In July of the same year he went out to New Zealand to act as engineer-in-chief and general manager of the Midland Railway, having undertaken to construct and work this important line. Although his efforts were successful, difficulties arose with the colonial government, involving long litigation and protracted delays, under which his health broke down, and in 1896 he returned to England for the fourth and last time. His death took place in London on 9th January 1898 at the age of forty-six. He became a Member of this Institution in 1883, and was also a Member of the Institution of Civil Engineers, and a Fellow of the Royal Society of Edinburgh.

ELECTRIC TRACTION.

Plate 1.

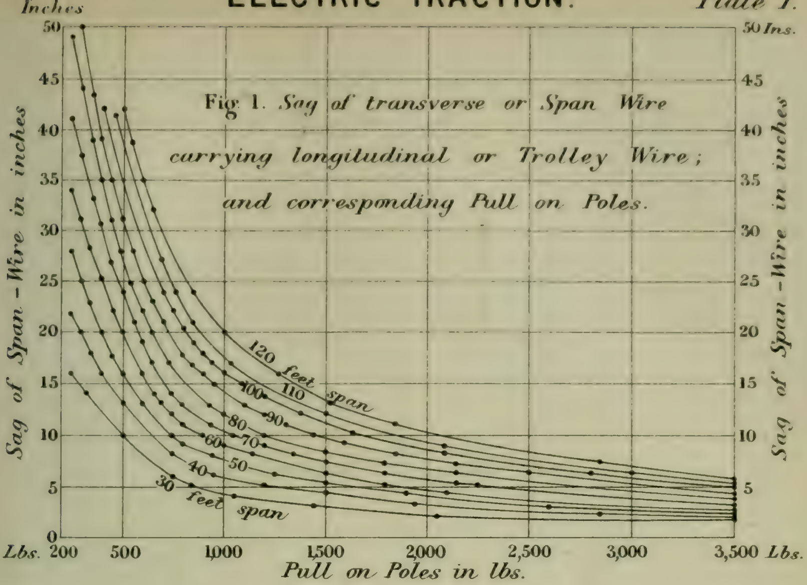


Fig. 1. *Sag of transverse or Span Wire carrying longitudinal or Trolley Wire; and corresponding Pull on Poles.*

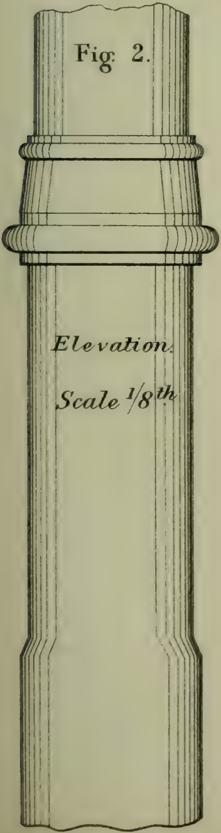


Fig. 2.

Elevation.

Scale 1/8th.

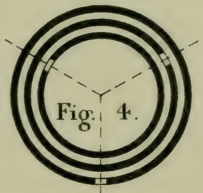


Fig. 4.

Tubular Poles with SSS *joints.*

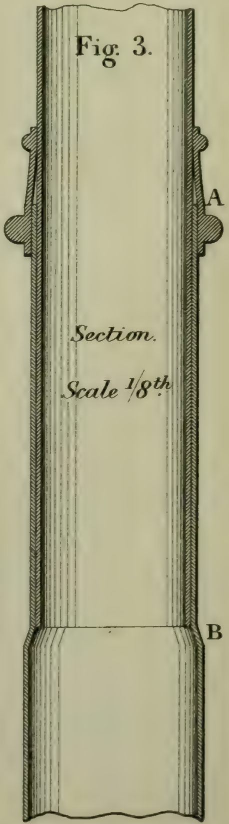


Fig. 3.

Section.

Scale 1/8th.

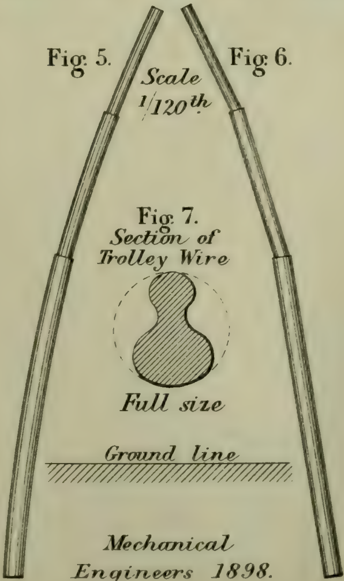


Fig. 5.

Fig. 6.

Scale 1/120th.

Fig. 7.
Section of Trolley Wire

Full size

Mechanical Engineers 1898.

ELECTRIC TRACTION.

Truck with extended spring-base.

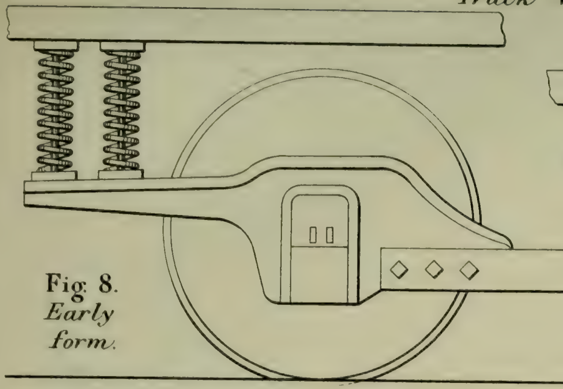


Fig: 8. *Early form.*

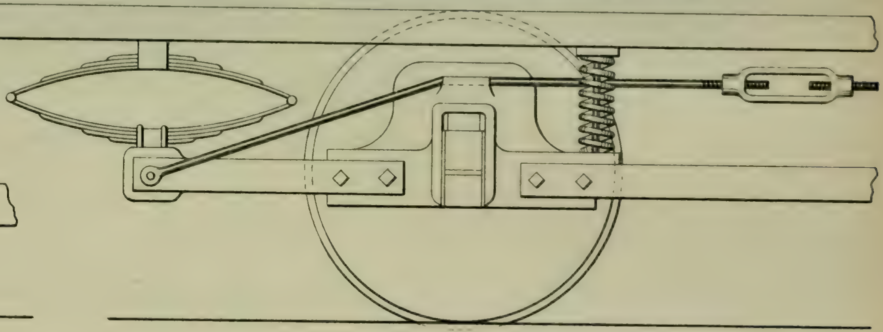


Fig: 9. *Trussed with Straining Rods.*

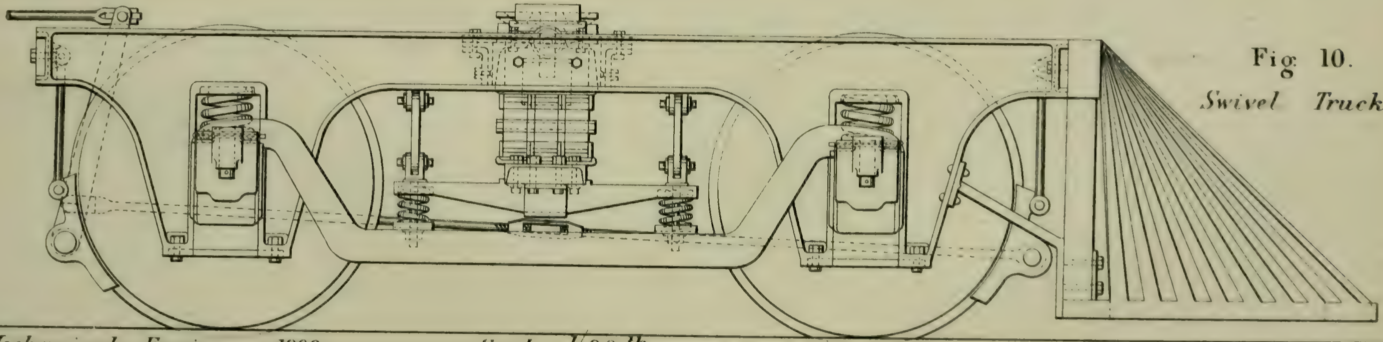
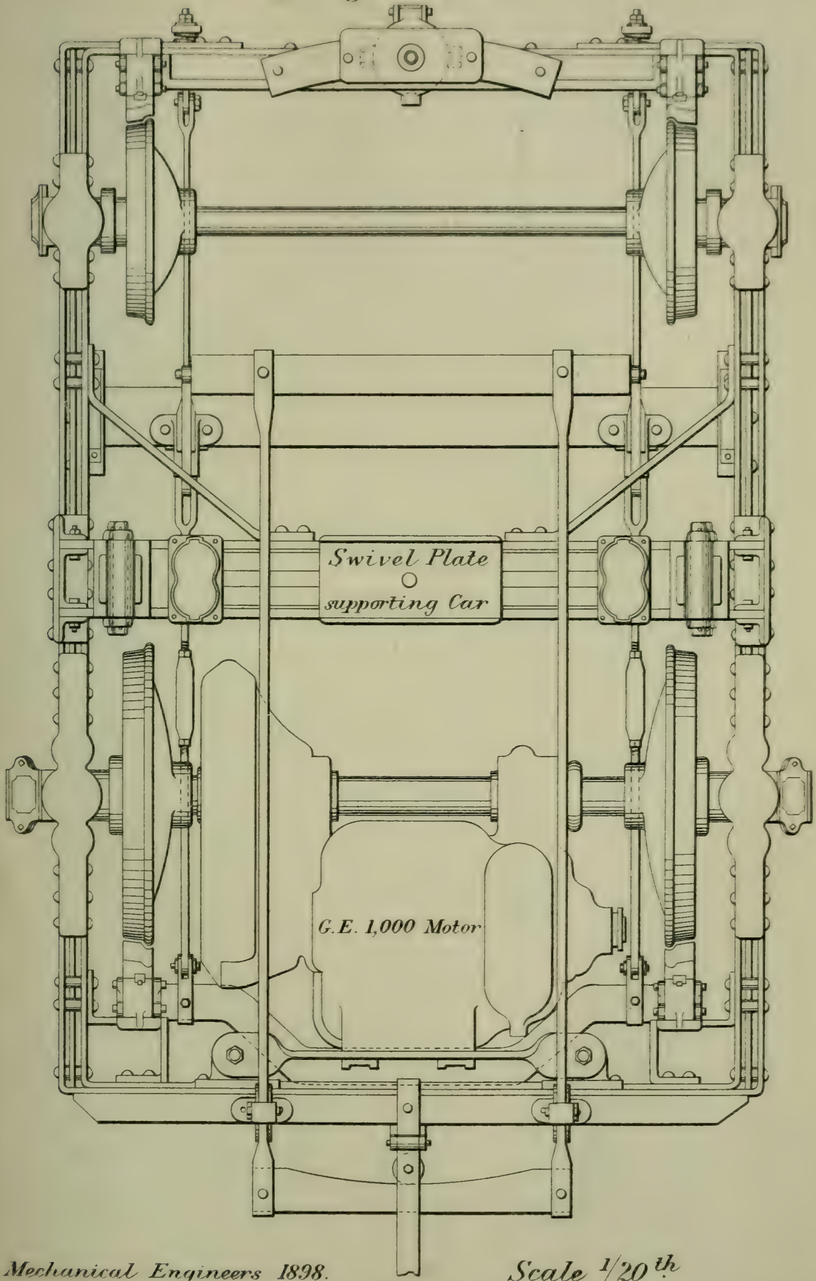


Fig: 10. *Swivel Truck.*

Scale 1/20th.

Maximum-Traction Truck.

Fig. 11. *Plan.*



Scale 1/20th.

ELECTRIC TRACTION.

Maximum - Traction Truck.

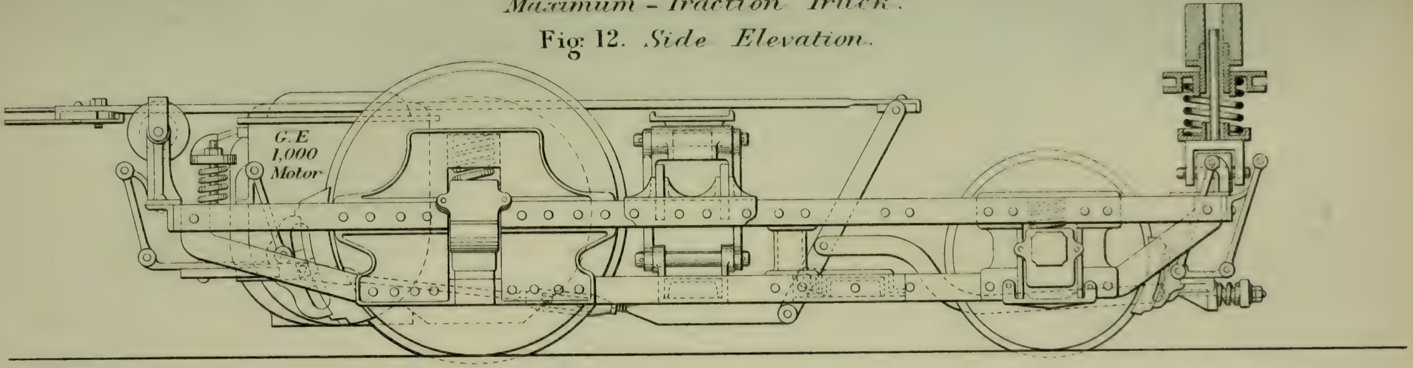
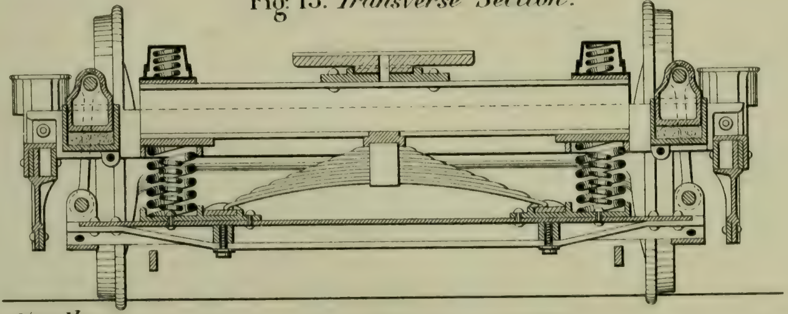


Fig: 12. *Side Elevation.*

Fig: 13. *Transverse Section.*



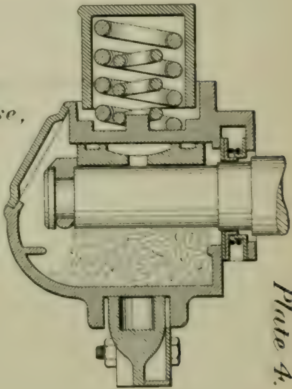


Fig: 14. *Axle-box using grease, for Cantilever Truck.*

Scale 1/20th.

Mechanical Engineers 1898.

Plate 4.

ELECTRIC TRACTION.

Extra Long Cantilever Extension Truck.

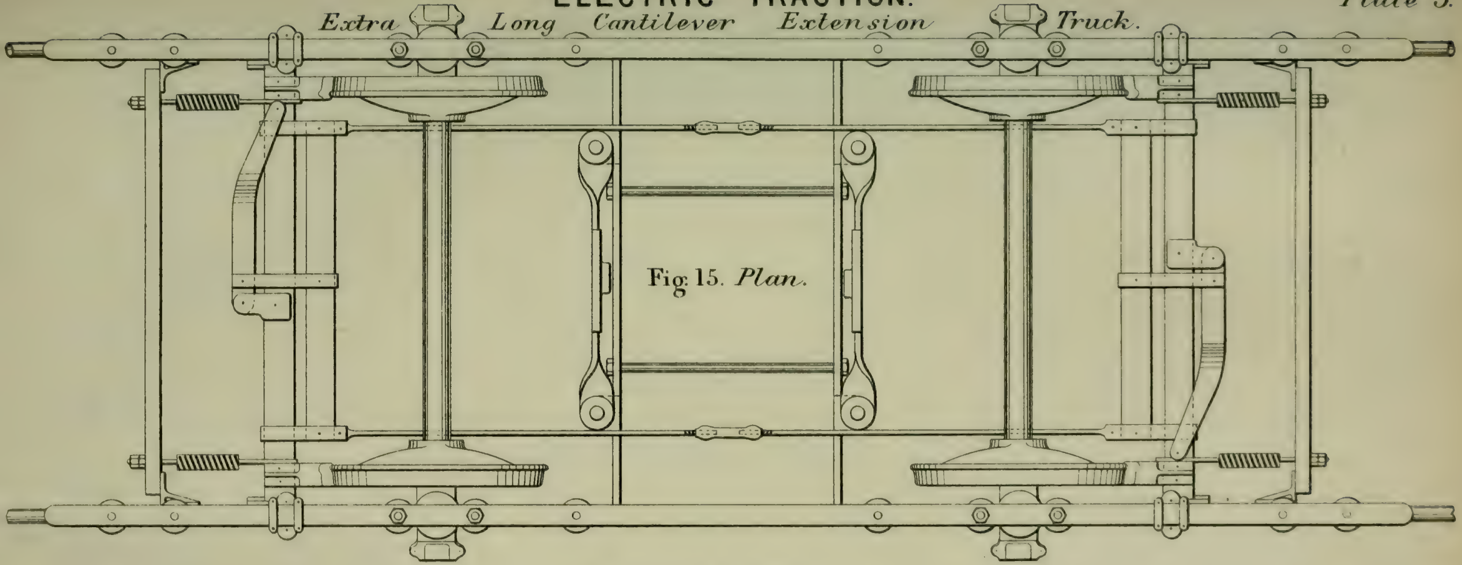
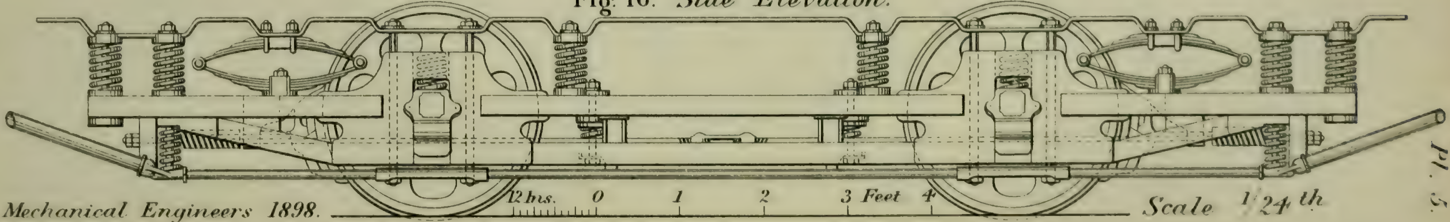


Fig. 15. *Plan.*

Fig. 16. *Side Elevation.*



Scale 1/24th

Mechanical Engineers 1898.

ELECTRIC TRACTION.

Plate 6.

Suspension of Motors.

Fig: 17. *Nose Suspension.*

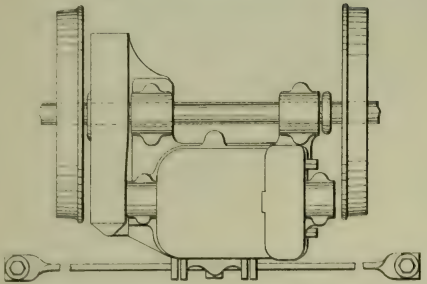


Fig: 19. *Side-Bar Suspension.*

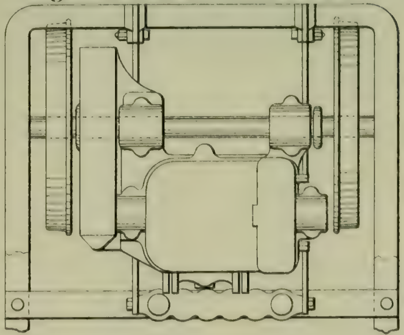


Fig: 21. *Yoke Suspension.*

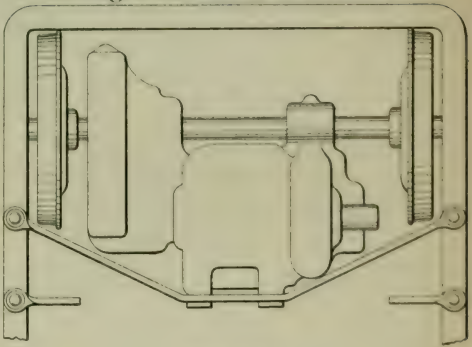


Fig: 18.

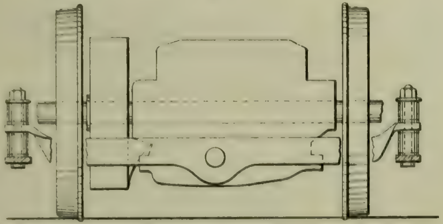


Fig: 20.

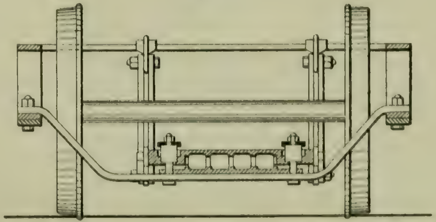
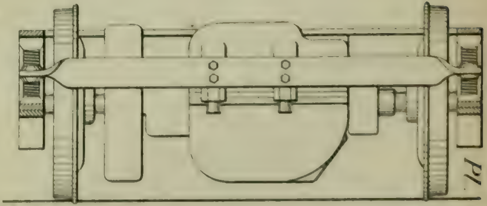


Fig: 22.



Mechanical Engineers 1898.

Scale 1/30th

Pl. 6.

ELECTRIC TRACTION.

Cylinder with Single Piston - Valve.

Fig: 23. *Transverse Section at* XX.

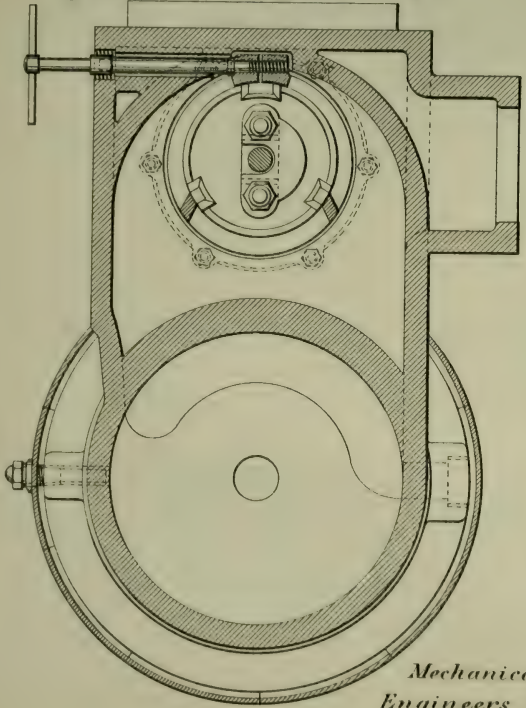
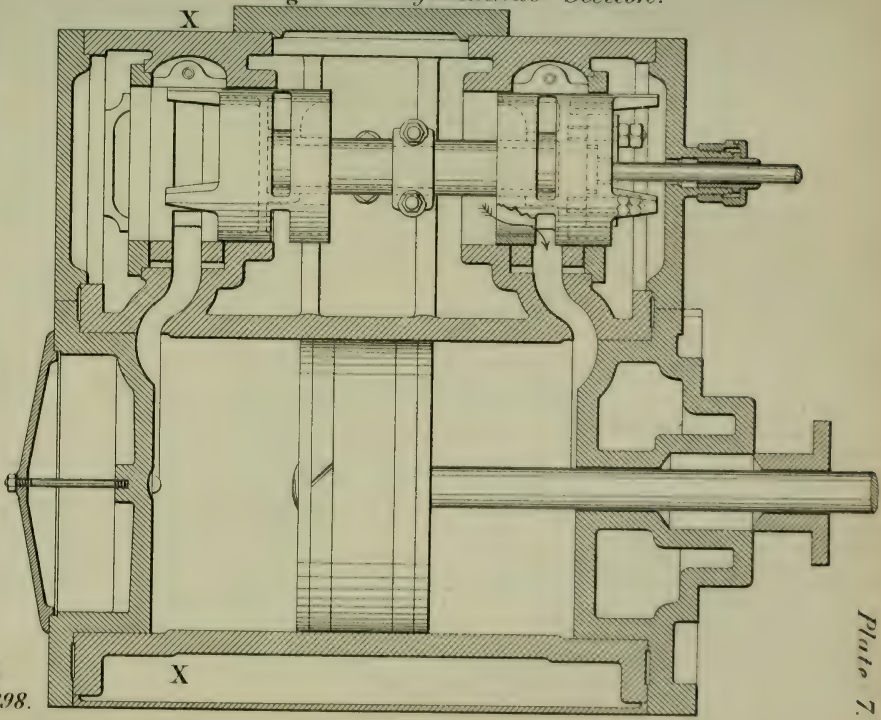
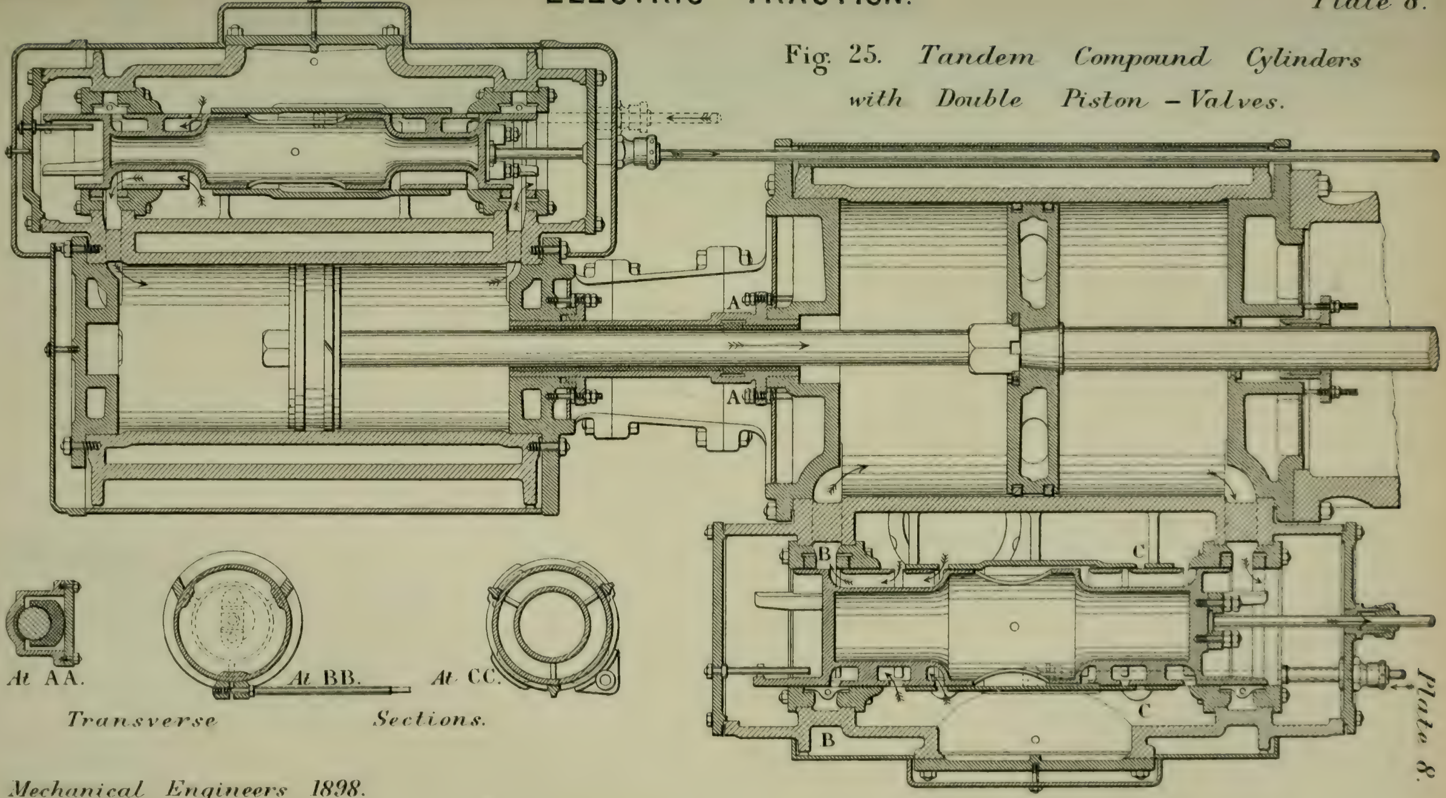


Fig: 24. *Longitudinal Section.*



Mechanical Engineers 1898.

Fig. 25. *Tandem Compound Cylinders with Double Piston-Valves.*



Transverse Sections.

Plate 8.

Mechanical Engineers 1898.

ELECTRIC TRACTION.

Fly-wheels.

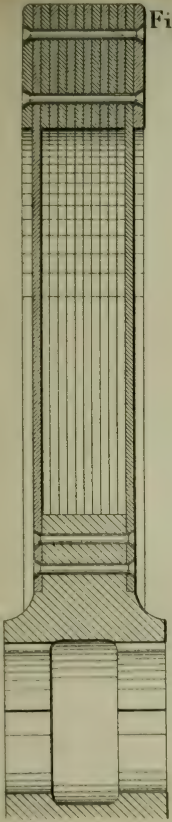


Fig: 26.

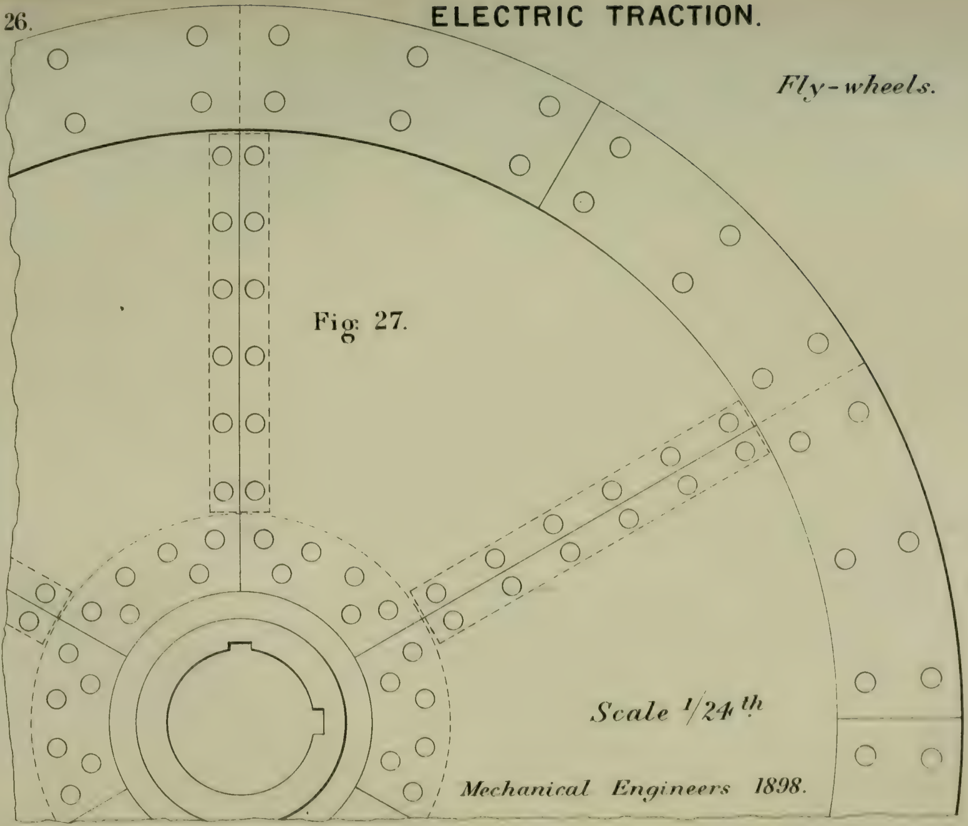


Fig: 27.

Scale 1/24th.

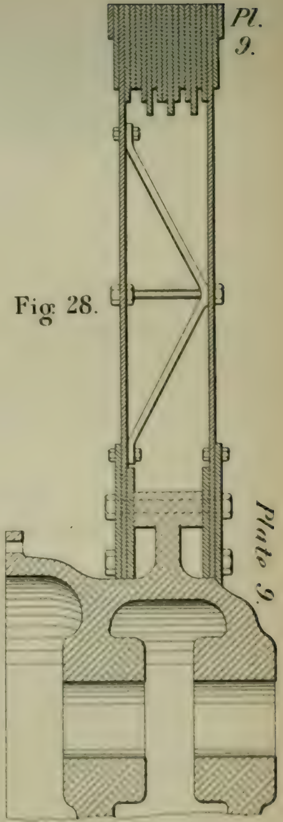


Fig: 28.

Plate 9.

Mechanical Engineers 1898.

Fig. 29. *General Electric* 800 *Motor, rated* 25 *horse-power, having* 800 *lbs. torque with* 33-*inch wheels.*

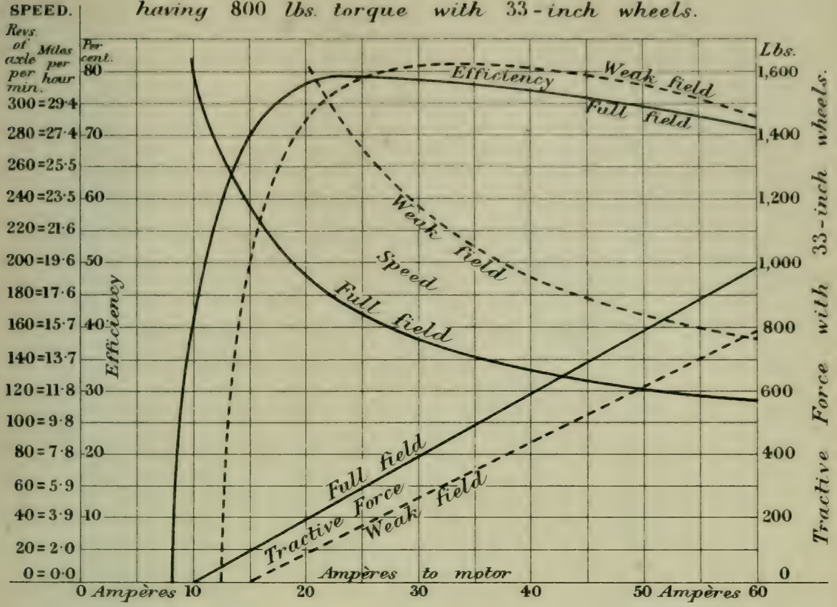
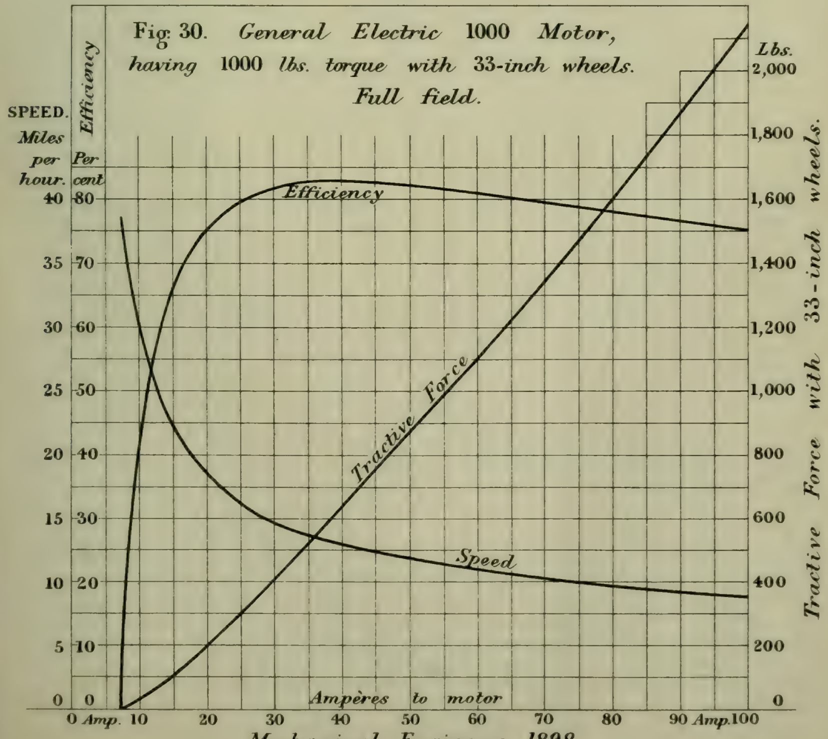


Fig. 30. *General Electric* 1000 *Motor, having* 1000 *lbs. torque with* 33-*inch wheels. Full field.*



Nº 46 Motor, 500 volts, rated 25 horse-power.

Fig. 31. *Horse-power, and Efficiency.*

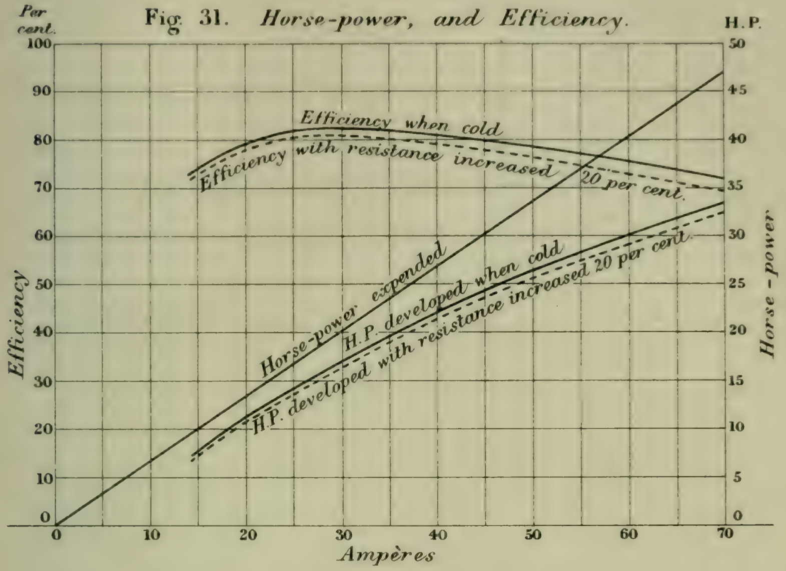
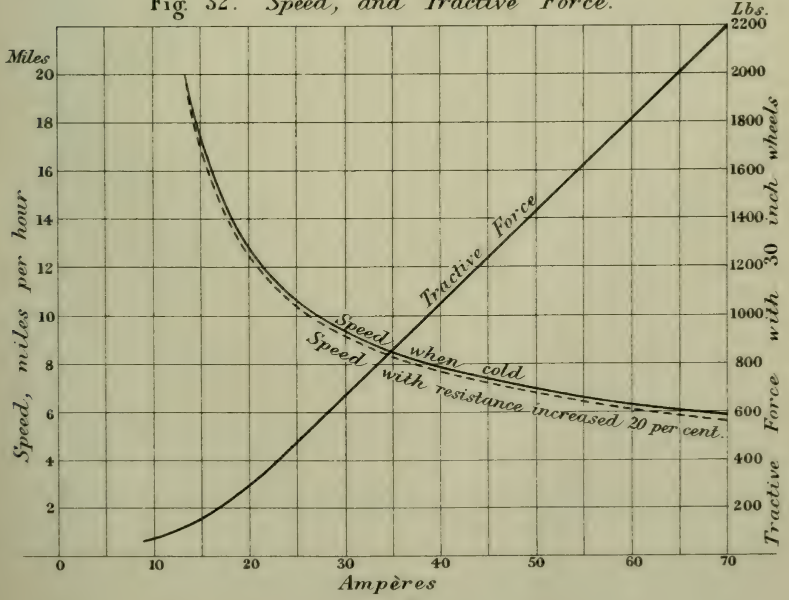


Fig. 32. *Speed, and Tractive Force.*



Compound Generators.

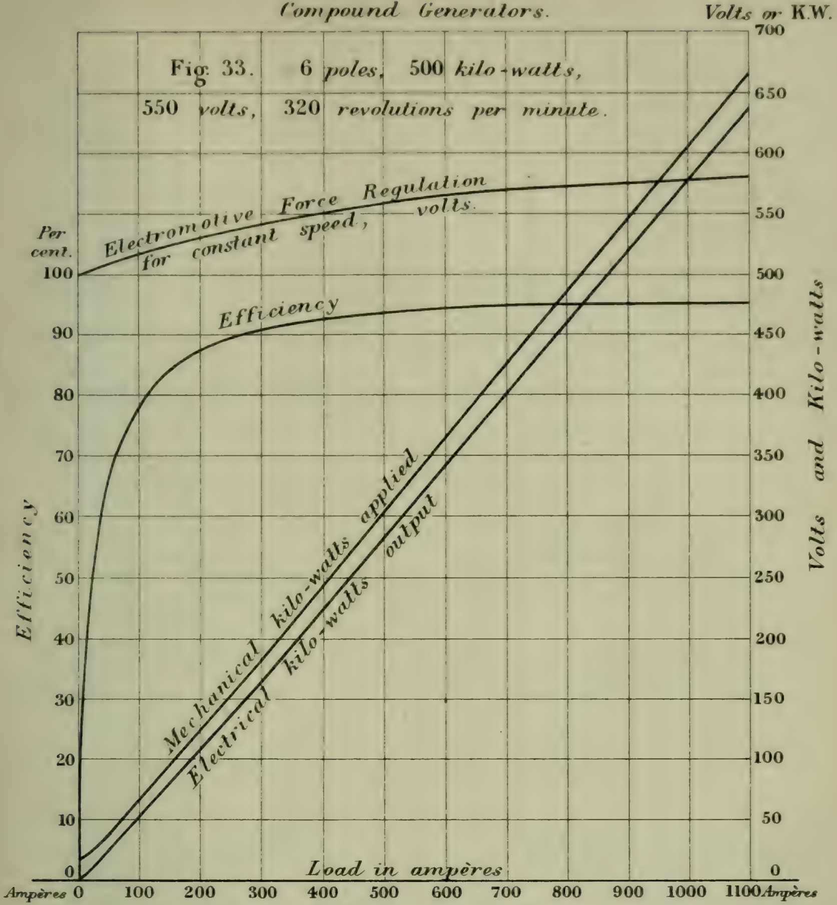
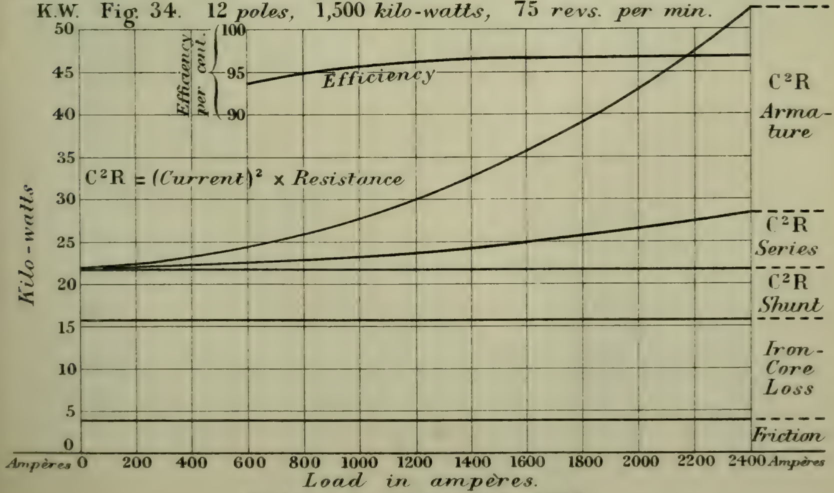


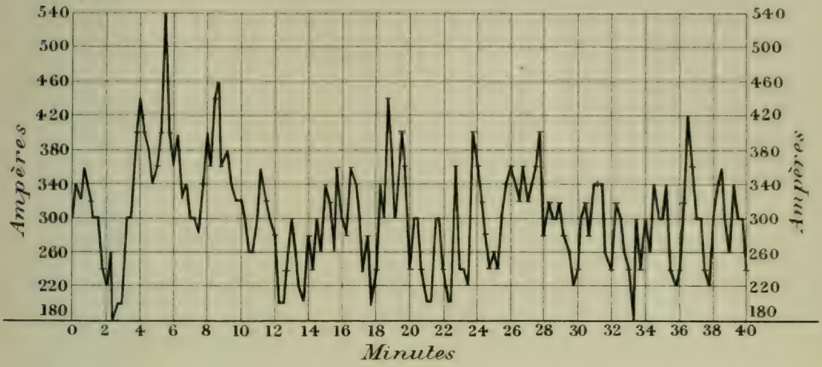
Fig. 33. 6 *poles,* 500 *kilo-watts,* 550 *volts,* 320 *revolutions per minute.*

Fig. 34. 12 *poles,* 1,500 *kilo-watts,* 75 *revs. per min.*



Mechanical Engineers 1898.

Fig: 35. *Electric Current supplied to an English Tramway.*



Moscrop Recorder Diagrams
from Gas Engine running light at 150 *revolutions per minute.*

Fig: 36. *Two Cast-Iron Fly-wheels* $5\frac{1}{2}$ *feet diameter.*
Weight of Rims 1470 + 1470 = 2940 *lbs.*
Total Weight of Wheels 1670 + 1670 = 3340 *lbs.*
Eleven impulses per minute.

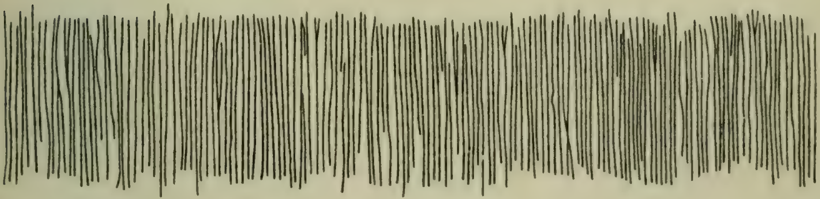
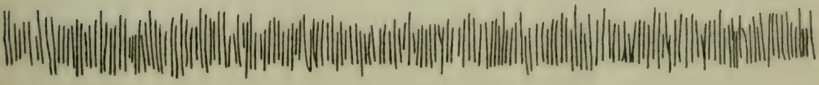
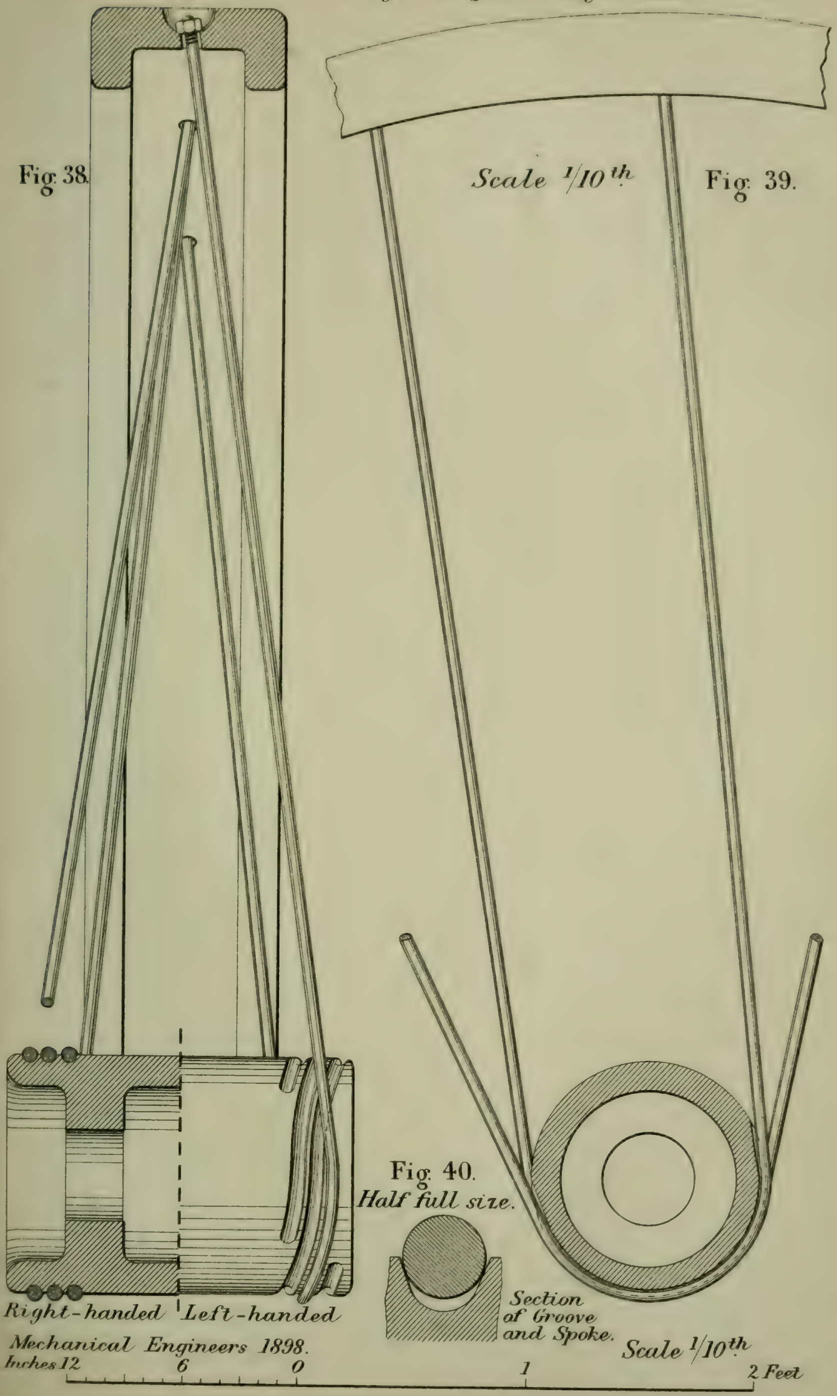


Fig: 37. *One Cast-Iron Fly-wheel* $5\frac{1}{2}$ *feet diameter,*
and one Tangent-Spoke Fly-wheel 10 *feet diameter.*
Weight of Rims 1470 + 2600 = 4070 *lbs.*
Total Weight of Wheels 1670 + 2900 = 4570 *lbs.*
Thirteen impulses per minute.



ELECTRIC TRACTION. *Plate 14.*

High-speed Tangent-spoke Fly-wheel.



Mechanical Engineers 1898.

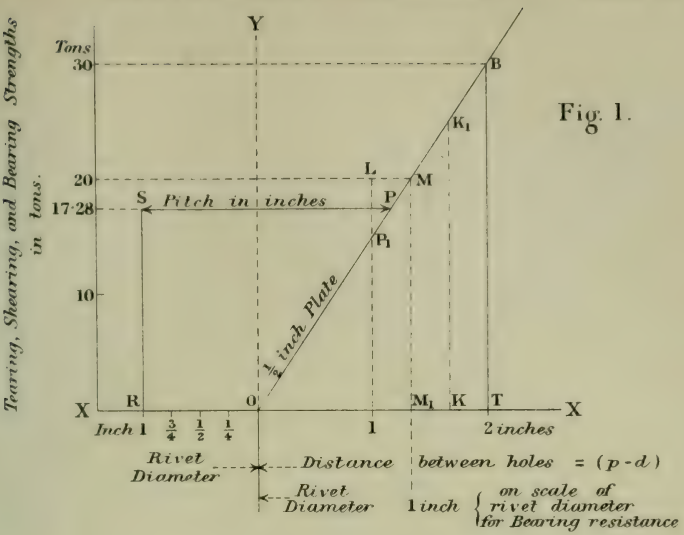


Fig. 1.

Tearing, Shearing, and Bearing Strengths in tons.
Tons
30
20
17·28
10
Y
B
K₁
L
M
S
Pitch in inches
P
P₁
½ inch Plate
X
R
O
M₁
K
T
X
Inch 1
¾
½
¼
1
2 inches
Rivet Diameter
Distance between holes = (p - d)
Rivet Diameter
1 inch { on scale of rivet diameter for Bearing resistance

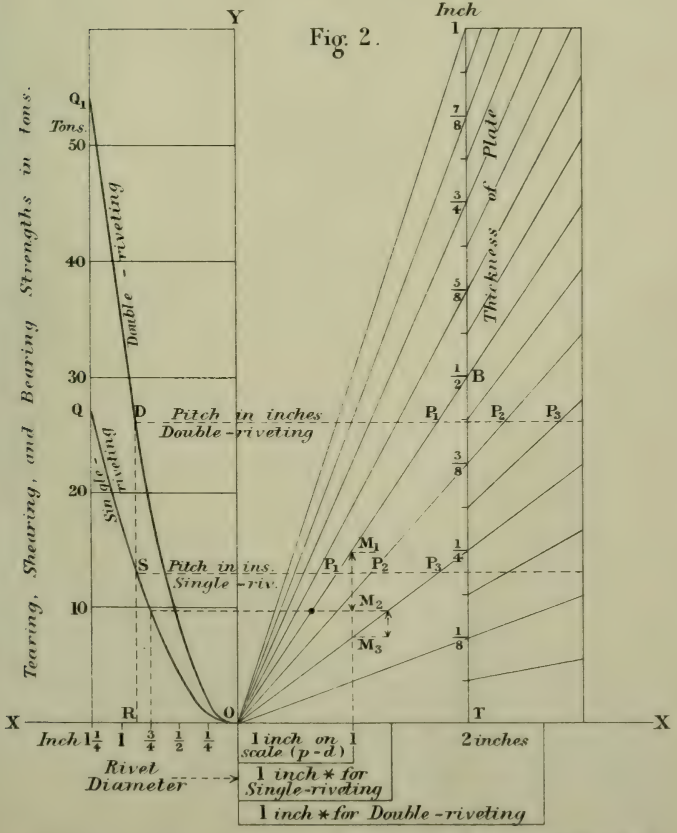


Fig. 2.

* { on scale of rivet diameter for Bearing resistance } *

Fig. 3.

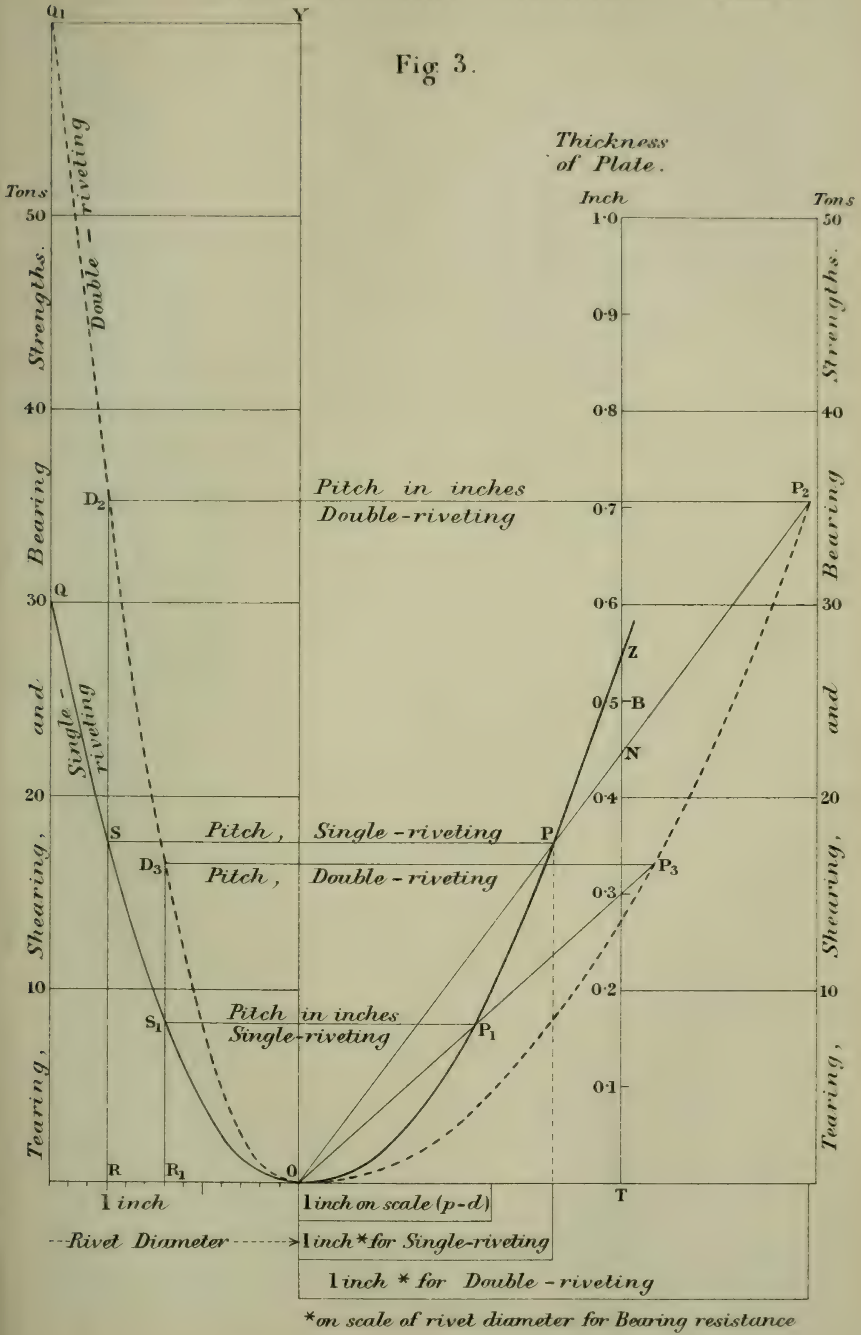
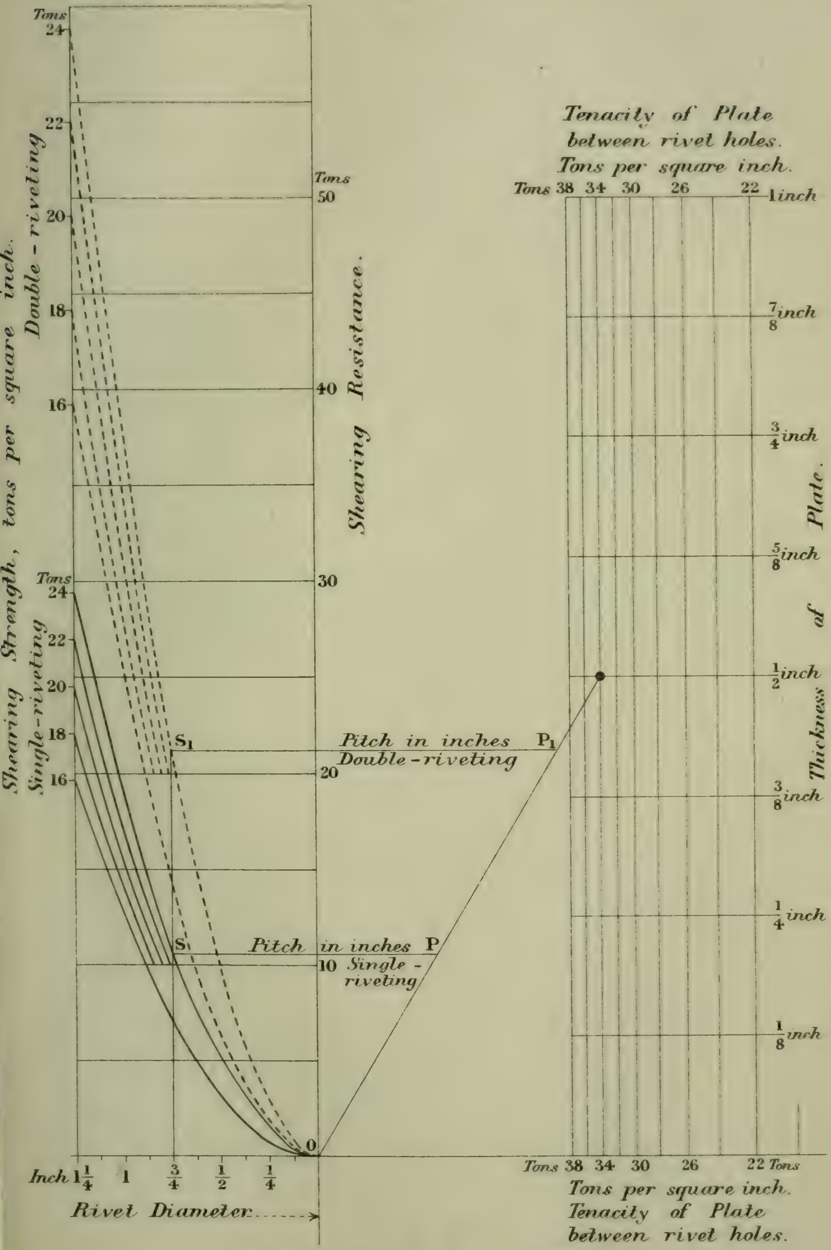

Q1
Y
Thickness of Plate.
Inch
Tons
50
40
30
20
10
1·0
0·9
0·8
0·7
0·6
0/5
0·4
0·3
0·2
0·1
Strengths.
Bearing
and
Shearing,
Tearing,
Double - riveting
Single - riveting
D2
Q
S
D3
S1
R
R1
O
T
Z
B
N
P
P1
P2
P3
Pitch in inches
Double-riveting
Pitch, Single-riveting
Pitch, Double-riveting
Pitch in inches
Single-riveting
1 inch
1 inch on scale (p-d)
--Rivet Diameter-------->1 inch * for Single-riveting
1 inch * for Double-riveting
*on scale of rivet diameter for Bearing resistance

Fig. 4.


Tons
24
22
20
18
16
Double-riveting
Shearing Strength, tons per square inch.
Tons
24
22
20
18
16
Single-riveting
Tons
50
40
30
20
10
Shearing Resistance.
S₁
Pitch in inches
P₁
Double-riveting
S
Pitch in inches
P
Single-riveting
O
Inch 1¼
1
¾
½
¼
Rivet Diameter
Tenacity of Plate between rivet holes. Tons per square inch.
Tons 38 34 30 26 22
1 inch
⅞ inch
¾ inch
⅝ inch
½ inch
⅜ inch
¼ inch
⅛ inch
Thickness of Plate.
Tons 38 34 30 26 22 Tons
Tons per square inch. Tenacity of Plate between rivet holes.

The Institution of Mechanical Engineers.

PROCEEDINGS.

April 1898.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 27th April 1898, at Half-past Seven o'clock p.m.; Samuel W. Johnson, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following ninety-three candidates were found to be duly elected:—

MEMBERS.

Arnold, Joseph Albert,	Derby.
Bamford, Robert George,	Madras.
Bancroft, Francis James,	Hull.
Beard, Arthur Charles,	London.
Beesly, Gerald,	Birmingham.
Campbell, Hugh,	Halifax.
Capron, Athol John,	Erith.
Coker, Ernest George,	London.
Cooper, Henry,	Sheffield.
Cowens, William Edward,	Gateshead.
Donaldson, Hay Frederick,	Woolwich.
Drummond, George William,	Glasgow.
Drummond, Peter,	Inverness.
Gibson, George Henry,	Liverpool.

Hammett, John George,	Bombay.
Heath, Ashton Marler,	London.
Hobbs, Charles James,	London.
Hudson, Francis James,	Derby.
Irwin, Delacherois Hastings,	Manchester.
Iveson, Thomas Gill,	Derby.
Jackson, Algernon Brooker,	London.
Lewis, Joseph Slater,	Manchester.
Lobnitz, Fred,	Renfrew.
McCowen, Victor A. H.,	Belfast.
Micklewright, William,	Walsall.
Mills, George Pilkington,	Nottingham.
Moulton, Arthur Johnson,	Derby.
Naylor, Tom Hyde,	South Bank, Yorks.
Peet, William Gadsby,	Derby.
Powrie, William,	London.
Robinson, James Armstrong,	Wolverhampton.
Sillar, Arthur Molyneux,	London.
Smart, Leslie Sanderson,	Liverpool.
Smith, John William,	Derby.
Smith, Tom Graves,	Stroud, Gloucestershire.
Smith, Walter Mackersie,	Gateshead.
Spence, Wilfrid L.,	Wolverhampton.
Stevenson, Hew,	London.
Urie, Robert Wallace,	London.
Watson, John Warden,	London.
Whitaker, Alfred,	Highbridge, Somerset.
Winn, Charles Reginald,	Birmingham.
Woollen, Thomas Henry,	Birmingham.

ASSOCIATE MEMBERS.

Acfield, Wilfred Cosens,	London.
Barber, Thomas Walter,	London.
Bouts, Thomas,	London.
Briggs, Herbert,	Johannesburg.
Bulfin, Ignatius,	Bournemouth.

Cameron, Robert Barr,	Brighton.
Carr, James John William,	Birmingham.
Cleave, Arthur Harold Wyld,	London.
Davies, Hugh,	London.
Donne, Frederick Edward Mowbray,	Derby.
Dowson, Robert Manning,	Derby.
Edwards, Edgar Llewellyn,	Birmingham.
Ellis, Jesse,	Maidstone.
Enock, Donald,	Dartmouth.
Fletcher, Harold Clarkson,	Johannesburg.
Gass, John,	London.
Graham, Hubert Berger,	London.
Herschmann, Arthur Julius,	Erith.
Hill, Alfred Percy,	Sheffield.
Honiball, Charles Roland,	Liverpool.
Inglis, William Rowland Hugh,	Frodingham.
Jackson, Robert Hiram,	Manchester.
Johnson, Walter Wroe,	Leeds.
Lund, John,	London.
Malcolm, John,	London.
Ogden, Cuthbert Charles,	Rochdale.
Parsons, Harry,	Coventry.
Pillatt, Andrew,	Nottingham.
Ravenhill, William Arthur,	Madras.
Roots, James D.,	London.
Russell, Bridgman,	London.
Smith, Thomas John,	Hanley, Staff.
Snow, John,	Sheffield.
Statham, Frederick Benjamin,	Manchester.
Thain, William Arthur,	Carnarvon.
Wolff, Charles Ernest,	Derby.

ASSOCIATES.

Brown, Ernest Frederick,	London.
Leechman, George Douglas,	Coventry.
Warner, Ashby William,	Newcastle-on-Tyne.

GRADUATES.

BELL, FRANK,	Derby.
FRASER, WILLIAM STUART,	Horwich.
GORDON, DOUGLAS,	London.
GREEN, HARRY HEWLETT RICHARD,	London.
MARIA, HORACIO SANTA,	Liverpool.
MAYES, HOWARD,	West Cowes.
PAYNE, FRANK GERVAS,	Lincoln.
PHILLIPS, WALTER PATRICK FREAR,	London.
RENNIE, JOHN ASSHETON,	London.
STEINMETZ, ARTHUR SAMLER BERNARD,	Bedford.
WARDLE, FRANK HAROLD,	Nottingham.

The PRESIDENT announced that, in consequence of the death of Sir Benjamin A. Dobson, Member of Council, the vacancy thereby occurring had been supplied by the Council, who had appointed Mr. Henry Lea, of Birmingham, as a Member of Council for the present year, his name being the next highest in the voting for the election at the Annual General Meeting. Agreeably with the articles of association, he would retire at the next Annual General Meeting, and would be eligible for re-election.

The PRESIDENT then delivered his Inaugural Address: after which the Discussion was resumed upon the "First Report to the Gas-Engine Research Committee," by Professor FREDERIC W. BURSTALL, of Birmingham, which had been read and partly discussed at the previous Meeting.

Shortly before Ten o'clock the Meeting was adjourned to Friday evening. The attendance was 130 Members and 57 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Friday, 29th April 1898, at Half-past Seven o'clock p.m.; SAMUEL W. JOHNSON, Esq., President, in the chair.

The following Paper was read and discussed:—

"Steam Laundry Machinery"; by Mr. SIDNEY TEBBUTT, of Leamington.

The President proposed a vote of thanks to the Institution of Civil Engineers for their kindness in allowing the use of their rooms for the Meeting of this Institution. For many years past we had been greatly indebted to them for their courtesy and generosity in lending their magnificent lecture room for our meetings, during the time that we had no room of our own.

The vote of thanks was passed unanimously.

The Meeting then terminated shortly before Ten o'clock. The attendance was 46 Members and 31 Visitors.

ANNIVERSARY DINNER.

The ANNIVERSARY DINNER of the Institution was held at the Freemasons' Tavern, Great Queen Street, Lincoln's Inn Fields, on Thursday evening, 28th April 1898, and was largely attended by the Members and their friends. The President occupied the chair; and the Guest of the evening was the Right Honourable the Earl of Halsbury, P.C., Lord High Chancellor. The following Guests also accepted the invitations sent to them, although those marked with an asterisk * were unavoidably prevented at the last from being present. The Right Hon. Lord Belper, P.C., Captain of the Hon. Corps of Gentlemen-at-Arms; the Right Hon. Lord Strathcona and

Mount Royal, G.C.M.G., High Commissioner for Canada; His Excellency Takaaki Kato, Envoy Extraordinary and Minister Plenipotentiary of the Empire of Japan; Admiral Edward Field, C.B., M.P.; Sir Richard E. Webster,* G.C.M.G., Q.C., M.P., Attorney-General; Sir Henry G. Bergne, K.C.M.G.; Sir T. Salter Pyne, C.S.I., Engineer-in-Chief to H.H. the Ameer of Afghanistan; Sir A. Seale Haslam, Chairman of the Local Committee, Derby Summer Meeting; Sir Henry H. Bemrose, M.P.; Colonel Herbert Jekyll, C.M.G., R.E., Secretary, Royal Commission of Paris Exhibition 1900; Professor W. C. Roberts-Austen, C.B., F.R.S., Honorary Life Member; Professor W. Cawthorne Unwin, F.R.S., Honorary Life Member; Professor D. E. Hughes, F.R.S.

The Right Hon. W. L. Jackson, P.C., M.P., Chairman of the Great Northern Railway; Sir Ernest Paget, Bart.,* Chairman of the Midland Railway; Sir James Kitson, Bart., M.P.; Major Sir Francis A. Marindin, K.C.M.G., R.E., Senior Inspector of Railways, Board of Trade; Sir Charles Scotter; Sir Henry Oakley,* Chairman of the Central London Railway; Mr. Wyndham S. Portal,* Chairman of the London and South Western Railway; Mr. George J. Armytage, Chairman of the Lancashire and Yorkshire Railway; Mr. J. Staats Forbes, Chairman of the London, Chatham and Dover Railway; Lieut.-Colonel Horatio A. Yorke, R.E., Inspector of Railways, Board of Trade; Mr. Charles Thomas, Deputy Chairman of the Midland Railway; Mr. Frederick Harrison, General Manager of the London and North Western Railway; Mr. George H. Turner, General Manager of the Midland Railway; Mr. J. L. Wilkinson,* General Manager of the Great Western Railway; Mr. William Pollitt, General Manager of the Great Central Railway; Mr. J. A. McDonald,* Chief Engineer of the Midland Railway; Mr. T. G. Clayton, Carriage and Wagon Superintendent of the Midland Railway.

Mr. William H. Preece, C.B., F.R.S., President of the Institution of Civil Engineers; Mr. Henry Webb,* President of the Manchester Association of Engineers; Mr. Tom Westgarth,* President of the Cleveland Institution of Engineers; Mr. Joseph W. Swan,* F.R.S., President of the Institution of Electrical Engineers; Mr. Charles D. Abel, President of the Chartered Institute of Patent Agents; Colonel

Henry F. Swan,* President of the North-East Coast Institution of Engineers and Shipbuilders; Mr. John A. F. Aspinall, President of the Institution of Junior Engineers; Mr. John Inglis,* LL.D., President of the Institute of Marine Engineers; Dr. J. H. T. Tudsbery, Secretary of the Institution of Civil Engineers; Mr. F. H. Webb, late Secretary of the Institution of Electrical Engineers; Mr. Alfred Bache, late Secretary of the Institution of Mechanical Engineers; Mr. R. Mountford Deeley and Mr. George J. Pratt, Honorary Secretaries of the Local Committee, Derby Summer Meeting.

Mr. James S. Beale,* Honorary Solicitor; Professor T. Hudson Beare, F.R.S.E.; Mr. W. G. R. Bousfield; Professor F. W. Burstall; Mr. William Dunk*; Mr. Harry Lee Millar, Treasurer; Mr. Basil Slade; Mr. Sidney Tebbutt; Mr. C. J. Wilson, F.I.C.

The President was supported by the following Officers of the Institution:—*Past-Presidents*, Sir Frederick Bramwell,* Bart., D.C.L., LL.D., F.R.S.; Sir Edward H. Carbutt, Bart.; Mr. Jeremiah Head; and Mr. E. Windsor Richards. *Vice-Presidents*, Sir Douglas Galton,* K.C.B., D.C.L., LL.D., F.R.S.; Mr. Arthur Keen; Sir William H. White, K.C.B., LL.D., F.R.S. *Members of Council*, Mr. John A. F. Aspinall; Mr. William Dean; Mr. Bryan Donkin; Mr. Edward B. Ellington; Mr. H. Graham Harris; Mr. Henry Lea; Mr. T. Hurry Riches; Mr. John I. Thornycroft, F.R.S.; and Mr. A. Tannett Walker. At the President's request, Mr. L. Sterne occupied one of the vice-chairs.

After the usual loyal toasts, Sir Charles Scotter proposed that of "The Navy and the Army," which was acknowledged by Admiral Edward Field, C.B., M.P., and by Major Sir Francis A. Marindin, K.C.M.G., R.E. The toast of "Her Majesty's Ministers," proposed by Sir Edward H. Carbutt, Bart., Past-President, was acknowledged by the Right Hon. the Earl of Halsbury, P.C., Lord High Chancellor. The Right Hon. W. J. Pirrie, P.C., High Sheriff of County Antrim, proposed the toast of "The Houses of Parliament," which was acknowledged by the Right Hon. Lord Belper, P.C., Captain of the Hon. Corps of Gentlemen-at-Arms, and by the Right Hon. W. L. Jackson, P.C., M.P. The toast of "Britain beyond the Sea," proposed by Sir William H. White, K.C.B., LL.D., F.R.S., Director of Naval

Construction, Vice-President, was acknowledged by the Right Hon. Lord Strathcona and Mount Royal, G.C.M.G., High Commissioner for Canada. Sir A. Seale Haslam proposed the toast of "Foreign Nations," which was acknowledged by His Excellency Takaaki Kato, Envoy Extraordinary and Minister Plenipotentiary of the Empire of Japan. The toast of "The Railways of Great Britain and Ireland," proposed by Sir Henry H. Bemrose, M.P., was acknowledged by Mr. J. Staats Forbes, Chairman of the London, Chatham and Dover Railway. The remaining toast of "The Institution of Mechanical Engineers," proposed by Mr. George J. Armytage, Chairman of the Lancashire and Yorkshire Railway, was acknowledged by the President.

ADDRESS BY THE PRESIDENT,

SAMUEL WAITE JOHNSON, Esq.

The many excellent and valuable addresses which have been given from time to time by former Presidents of this Institution, embracing a great variety of subjects bearing upon Mechanical Engineering or connected therewith, have not, so far as I have been able to ascertain, included any dissertation on Railway Progress. A theme has therefore been left open, which I trust will be found of interest to the Members of this Institution generally; the more so because railways have been from their beginning, and are now, much indebted to the skill, ingenuity, and inventive genius of both civil and mechanical engineers, for their construction in the first instance, and for the efficiency of the work they are enabled to carry on by the use of locomotive and stationary engines and of machine-tools. Great advances have been made during the last forty or fifty years in the design and construction of locomotive engines and railway rolling stock, and of special workshop tools and appliances for the more rapid and economical production of the numerous parts necessary for the construction and renewal of such stock; and also in the adaptation of hydraulic-power machines, such as hydraulic cranes, hoists, traversers, capstans, coal-tipping machinery, etc., with which the work at our large railway goods warehouses, goods yards, wharves, and docks, is so successfully and smoothly carried on. How fully it is recognised that the true interests of railways are best served by encouraging mechanical engineers in their endeavours to produce labour-saving machinery and appliances, becomes abundantly evident on an inspection of the vast array of the most modern and most improved machinery with which the workshops of our principal railways are equipped. The history of the growth of railways is equally the history of the growth of mechanical engineering; for even in its latest development—the electrical production of power and light—we have not only railway stations, passenger coaches, and goods yards profusely lighted by electricity, but we have also both overhead and underground railways worked successfully by the same agency, and paying dividends to shareholders. I therefore purpose placing before you a short review of British Railway Progress, special reference being made to the Midland Railway, with which I have had the honour to be connected for nearly twenty-five years, as typical, in a great measure, of the progress of other lines of railway in this country.

For its successful development railway enterprise probably depends more upon the general prosperity of the country than any other commercial undertaking; and by its growth and extension it brings home to us, in a forcible manner, the great progress which has been made during the Victorian era. The growth of commerce doubtless results from the varying conditions of demand and supply, the former being dependent upon the varying wants of the people, and the latter upon their ability to do the work required for producing the articles in requisition at the time. By manual labour alone it would be impossible to turn out even a small fraction of the merchandise, manufactured goods, machinery, etc., which go to make up the great volume of traffic carried by our railways; or to move it with ease and celerity from the factory and workshop to the market, and then distribute it as required. To the invention of the steam engine, the gas engine, and other prime movers, we therefore owe the circumstance, that it is now possible to use power derived from natural sources for actuating our labour-saving appliances; and, by increasing many times the output per man, to construct at small cost and in large numbers articles that enable every one to enjoy comforts and luxuries, which at one time were within the reach of only a few.

The fact that this is entirely the result of the introduction of power-driven labour-saving machinery is not always appreciated, and even now the illusion is not entirely dispelled that labour-saving appliances throw manual labour out of employment; whereas the effect of their use is that, by securing greater production at less cost, a much larger demand results, and more hands are employed. The engineer who designs a machine which, without reducing the quality of the manufactured article, largely increases the output, is increasing the prosperity of the engineering trades, and should therefore be regarded as a benefactor to his country. Outside interference with the management of engineering and other workshops, which aims at limiting the output per man or per machine, partly by abolishing piecework and partly by placing the most skilful artisan on a level with the least skilful, is wrong, and retrograde in principle, for thereby the cost of production is necessarily increased. With the reasons why the demand for manufactured articles and raw materials fluctuates from time to time, but on the whole increases steadily from decade to decade, we have no immediate concern. It is sufficient for the manufacturer, the engineer, and the railway manager, to know that there has been a steadily increasing demand for such articles and materials, and that there is as yet no indication that anything more serious than a temporary falling off in this respect is probable for many years to come. The Board of Trade returns of the traffic carried on the railways of the United Kingdom show this clearly.

Our iron roads are the arteries and veins of the nation; and every variation in the streams of traffic that traverse them results from the action of some economic change, the development of which would be otherwise hardly measurable or perceptible. To the casual observer such business fluctuations as occur from time to time appear perhaps to follow no particular order or sequence; but judging from the Board of Trade returns, as shown in diagrams about to be referred to, the volume of railway traffic may be considered as one which increases in a very regular and definite manner. It is also clear, attempt to explain it how we may, that periods of good and bad trade have succeeded each other with marked regularity at about eight or nine years' intervals for the last forty years. This periodical variation in the volume of traffic carried manifests itself in the returns both for passengers and for goods and minerals.

Passenger Traffic.—Fig. 1, Plate 18, shows at a glance the variations in the annual volume of the passenger traffic of the United Kingdom (exclusive of season-ticket holders) which have occurred since the year 1854. Since 1862 the periodic growth has been a fairly steady one, amounting on the average, when corresponding years (since 1869) in each spell of depression or prosperity are compared, to an annual increase of about 24,725,000 passengers, the total for 1896 being 980,339,433. It must be remembered that we are here dealing with numbers which increase with time, owing partly to the opening of new lines and the increase of population, partly to the growing fondness for travel which so characterises modern years, partly to lower fares and greater facilities for getting from place to place, and partly to the effects which the fluctuations in trade have upon the spending or earning power of the people. It is remarkable that, in spite of many disturbing influences, the increase in the number of passengers carried should show such very regular fluctuations. In order to make these fluctuations clearer to the eye, mean curves have been drawn on the diagram through the points plotted, thus covering in some measure such disturbing effects as result from the opening of new lines and from strikes, etc. Taken together, the curves form a series of waves, of which the more rapidly rising sides mark periods of prosperity, and the less rapidly rising sides denote periods of depression.

The first prosperous period shown by the passenger returns begins about 1862; and the succeeding ones commence in the years 1870, 1879, and 1888. On the whole, since 1862 the increase has been wonderfully regular, the periods being generally most clearly marked when the figures for the United Kingdom are taken, and least regular when a single railway only is considered. This is seen by comparing Fig. 1 with Fig. 2, Plate 18, which shows the number of passengers (exclusive of season-ticket holders) carried each year by the Midland Railway; here the mean annual rate of increase from 1869 to 1896 is 1,116,827, and the total for 1896 is 45,721,786. It will be noticed that the periodical fluctuations of the curves on both diagrams agree closely; and that we are feeling at the present time, a little earlier than the curves would lead us to expect, the first effects of a period of prosperity. Since 1854 the number of passengers carried each year has increased about three times as rapidly as the mileage of the lines open. This has not only enabled a greater number of trains to be run, but has rendered it profitable to put on express through trains between all the more important centres of population.

Goods and Mineral Traffic.—Turning now to goods and mineral traffic, we find that the periodic fluctuations in its volume are somewhat similar to those which have been shown to occur in the passenger traffic. In Fig. 3, Plate 19, have been plotted the weights of merchandise and mineral traffic carried annually by the railways of the United Kingdom since 1872. By comparing one prosperous period with another since 1878, the mean annual rate of traffic increase works out at 8,318,453 tons. Although the variations which have taken place from year to year have been somewhat irregular, the mean curves put on the diagram show that the periods during which this kind of traffic rapidly increased correspond very closely with those during which there was a rapid growth of passenger traffic.

The returns of the Midland Railway goods and mineral traffic for a similar period, plotted to a larger scale in Fig. 4, Plate 19, show variations of a similar character. The periods of depression however, indicated by the merchandise and mineral traffic returns, are much more marked, and reach their greatest intensity a year or two earlier than do those shown by the passenger returns. Marked irregularities are also introduced by strikes, such as that in the coal trade in 1893, which produced so great an impression upon the mineral and goods traffic; as well as by other trade disputes.

Train Mileage.—To accommodate the steadily increasing number of passengers and weight of merchandise and minerals placed upon the railways, additional trains have had to be put on from time to time. Fig. 5, Plate 20, shows the increase this has caused in the train miles run on the railways of the United Kingdom; whilst Fig. 6, Plate 21, shows the Midland Railway train mileage and also mileage per engine, and gives a clear idea of the rate at which traffic has grown on this railway since 1873.

Since 1878, as will be seen from Table 1 (page 171), there has been on the railways of the United Kingdom an increase of 73·5 per cent. in the number of passengers carried, and of 71·1 per cent. in the train miles run; an increase of 72·4 per cent. in the tonnage of goods and minerals carried, and of only 48·7 per cent. in the train miles. The ratio between the train mileage and the number of passengers or tons of goods carried by the different railways varies considerably, as shown in Figs. 7 and 8, Plates 22 and 23, in which have been plotted the tons carried per train mile by a number of English and Welsh railways.

Financial Progress.—The improvement in the traffic receipts has been so considerable that the trunk lines which connect or run into large industrial centres have been able to pay their way most satisfactorily. The smaller lines, largely serving as feeders for them, and in many instances being unable to pay dividends, have been absorbed by the larger railways. Alterations in the values of monetary standards, and other changes such as the conversion of stock, have rendered it difficult, if not impossible, to show with precision from the Board of Trade returns the financial progress made by railways. No doubt comparisons instituted for the purpose of ascertaining variations of profit and loss from year to year—that is, comparisons between the figures for consecutive years—are valid; but, when they are instituted between the figures for more widely separated intervals of time, they do not necessarily indicate correctly the actual progress achieved. Thus, when we say that the capital of the railways in the United Kingdom was £1,029,475,335 in 1896 and only £286,068,794 in 1854, the exactness of the impression conveyed to the hearer must depend to a large extent upon his knowledge of financial history, because the nominal capital accounts vary from time to time, owing to conversions of stock, revisions of rates of interest, amalgamations of railways, and other causes. A much clearer mental view of the progress made by railways is therefore gained from the considerations previously referred to than from any financial statement.

Cost of Power.—There is a considerable difference in the cost of working a mineral, a goods, or a passenger train; and to obtain the actual total cost per train mile for power for each class of traffic is a difficult matter. In a case brought before the Railway Commissioners, the Midland Company, in order to justify certain rates charged for carriage, found it necessary to ascertain as nearly as possible the separate costs per train mile of engine power for working passenger, goods, and mineral trains. The details of these costs are not separately recorded in the company's books, inasmuch as, owing to the variable conditions of working and to the same engines and men being used for different kinds of trains, it is practically impossible to keep a separate account for each class of traffic; and only with much difficulty therefore could an approximate estimate be arrived at. The information for this estimate had to be obtained at considerable expense; and required the services of a staff of clerks for several weeks to extract the necessary particulars from drivers' returns, of which upwards of 17,000 had to be examined. The costs of working each class of traffic, as made out for this enquiry, are given in Table 2 (page 171) and plotted in Fig. 9, Plate 24. The method adopted for computing these costs was as follows. A section of 72 miles of line between Kettering and London was selected to represent fairly the average working of the whole system; and from the drivers' returns the detailed particulars of time occupied and of coal and stores consumed from the commencement to the end of the journey, by all train engines passing through that section for a period of four weeks in March and four weeks in September 1892, were carefully extracted, and classified under the three separate heads of passenger, goods, and mineral trains. Workings of too mixed a character to be so classified were disregarded. The numbers and mileages of the three classes of trains running through the section during these forty-eight days were thus found to be—

	Total Train Mileage.	Daily Average per Engine.
48 Passenger engines . . .	406,682	176 miles
64 Goods " . . .	393,157	128 miles
123 Mineral " . . .	564,664	95 miles

By this method the actual particulars of such elements in the running cost of engine power as are subject to variation according to the class of train worked—namely drivers' and firemen's wages, and coal and stores consumed—were ascertained separately for passenger, goods, and mineral trains.

In addition to the mileage worked by train engines, a mileage is accredited to such engines as are employed on pilot work, or which stand at stations ready to assist or work a train if required; and also to shunting engines which perform the necessary shunting of traffic in the goods yards and in the marshalling sidings throughout the line; and the working of such engines is an auxiliary expense to the running of train engines. In recording the work of these auxiliary engines, six miles per hour are allowed for shunting engines, and the same for pilot and bank engines, except that when the latter are engaged in assisting a train engine they are credited with the actual mileage run. This auxiliary mileage was classified under the heads of (*A*) mileage in connection with passenger trains, and (*B*) mileage in connection with goods and mineral trains. In this way it was ascertained that for the year 1892 the auxiliary mileage was (*A*) for passenger trains 13·07 per cent. of the passenger train mileage, and (*B*) for goods and mineral trains 38·73 per cent. of the goods and mineral train mileage. Therefore to each item of the running cost of train engines there was added for auxiliary expenses (*A*) 13·07 per cent. to passenger train engines, and (*B*) 38·73 per cent. to goods and mineral train engines.

The charges, shown in Table 2 (page 171), for the actual time occupied by the drivers and firemen of the trains, were based upon the average rates of wages paid. The cost of drivers' and firemen's wages per train mile for mineral trains is much greater than for either passenger or goods trains. This is largely due to the fact that an excessive amount of delay falls to the mineral train engines as compared with either of the other two classes, because mineral trains have to be shunted out of the way so as to give precedence both to passenger and to goods trains. This necessitates the provision of relief drivers and firemen, for releasing the mineral train drivers and firemen from their duties, to a much greater extent than is the case with either passenger or goods trains: the object being to limit, as far as possible, the hours of duty of the men to a maximum of twelve hours per day, in order to meet the Board of Trade requirements. Owing to the time lost in waiting and travelling, the provision of relief men is a very expensive item in the cost of drivers' and firemen's wages. This expense was divided between passenger, goods, and mineral trains, in proportion to the number of men relieved in each class, and it worked out as follows for relieving only :—

Passenger trains	0·03	penny per train mile
Goods ,,	0·28	,, ,, ,,
Mineral ,,	0·91	,, ,, ,,

The costs of wages and materials, for maintenance and renewals of engines, were taken at the average rates per train mile for the whole line; and from an extended experience of many years in the maintenance and renewal of locomotive engines, I am of opinion that this was a fair method of dealing with the maintenance and renewal charges for each of the three classes. The rates for power, submitted to the Railway Commissioners, were as follows :—

Passenger trains	6·94	pence per train mile
Goods ,,	9·29	,, ,, ,,
Mineral ,,	11·68	,, ,, ,,

These figures I am satisfied were as near an approximation to the actual costs as could be arrived at for the periods stated, and with the costs of materials and labour which were current in the year 1892.

Locomotive Expenditure.—There are many items of locomotive expenditure, the changes in the value of which from year to year are of considerable interest. Table 3 (pages 172–7) and Fig. 10, Plate 25, show the details of expenditure in the locomotive department of the Midland Railway for the twenty-four years from 1873 to 1896 inclusive, and they contain more complete information than can be gathered from any records published hitherto. The interval embraces periods of prosperity when the prices of fuel, stores, and materials were high, as well as periods of depression when prices were low and the demand limited. To give a clear idea of the variations which have occurred, Table 4 (pages 178–83) and Fig. 11, Plate 26, have been constructed, which show the cost per train mile of the several items. The greatest fluctuations, it will be noticed, have occurred in the cost of coal and coke, owing both to the changes in the price paid per ton, and also to the reduced consumption per train mile which has resulted from improvements in the locomotive stock, etc. The wages of drivers and firemen per train mile have been rising for a number of years, of late rather rapidly, owing to the relief system already referred to, which has been organized for preventing men from having to remain more than twelve consecutive hours on duty. It will also be noticed that as a rule, whilst the cost per train mile of the labour engaged in repairing and renewing the locomotive stock has increased, the cost of the material used has decreased. Labour-saving machinery has really cheapened the articles manufactured without diminishing the wages or number of the workmen; for the staff engaged per engine, as will be seen from Table 4, has fluctuated only slightly.

Distance Run and Speed.—Table 5 (pages 184–7) has been compiled to show the distances run and speeds of travelling on the Midland Railway since 1855. Here we have a number of links of various lengths between important towns, over which express trains were formerly or are now running. It will be noticed that in early days, although the runs were comparatively short, the speeds were fairly good. Recently however not only have the runs become much longer, but the speeds also have increased. In 1855 the longest run was 24 miles, and the booked speed 42·3 miles per hour. In 1897 the longest run was 124 miles, and the speed 52·0 miles per hour: a very considerable increase, having regard to the greater weight of modern trains. Stopping trains, as well as express trains, also show improvements in respect of increased speeds. Of course the whole of the acceleration is not due to increased locomotive power; it arises partly from the improved condition of the permanent way, the easing of sharp curves, etc. These increased speeds, and the greater volume of traffic passing over each line of rails, have been rendered possible and safe only by the introduction of powerful automatic brakes, and by improved systems of signalling. To both these items I shall have occasion to refer later on.

Locomotive Stock. — To work the increasing train mileage, considerable additions have been made to the locomotive stock. In 1873, as shown by Fig. 12, Plate 27, the locomotive ordinary stock of the Midland Railway numbered 1,040, and in 1897 it had risen to 2,327. The effects of periodic variations of trade are only slightly represented in these figures, because each locomotive has to do more work when trade is good than during times of depression.

The rapid strides which have been made in locomotive design and construction may be better illustrated by noting the progress realised by one or more of the larger lines, rather than by dealing with the locomotive stock of the whole kingdom; for the various types of engines used on the smaller lines and branches, both now and in the past, have not exhibited such great increases in weight and power as have those used for the express passenger and goods trains on the main trunk lines. The locomotive has come to assume its present form and construction by the continual improvement of its several parts, each alteration in design having resulted from the introduction of new materials, or from altered conditions of work; and all such alterations have had to be so carried out as to involve as small a departure as possible from previous practice. Unlike the roads and fuel of many foreign lines, the nature of the permanent way in this country, and the quality of coal here used, are such that it is possible to run with economy locomotives of simple design and well balanced proportions; and the result has been that few foreign express engines can compare favourably, either in regard to efficient working or from an artistic point of view, with those of British build.

The late Mr. Joseph Tomlinson, in his Presidential Address delivered before this Institution in May 1890, has already described and illustrated a large number of types of British locomotive engines as originally constructed and as now existing in this country. In order to avoid a repetition of what he has already so fully given and so clearly illustrated concerning locomotive development in general, I purpose showing in outline the advances made on the Midland

Railway during the last forty or fifty years, in the size, power, weight &c., of main-line standard engines. Few of the older lines have had less than twenty to thirty types and sizes of locomotives, the diversity being due principally to the varied designs favoured by the successive locomotive chiefs, and also to the fact that in early times it was the locomotive builders who provided such types of engines as they deemed most suitable for the traffic to be worked. Designs such as those of the "Crampton" and "Mail" locomotives have now almost disappeared from our lines; the old objections to high boilers have proved to be unsound; and, except on rack railways for mountainous districts, the connecting-rod is always coupled direct to a crank on one of the wheel axles. The following six types however are nowadays found all that is necessary for the working of an English railway.

First Type.—A single-driving passenger tender express engine with leading bogie is well suited for lines with gradients not exceeding 1 in 150. This class of engine is a great favourite with drivers of express trains. I may mention that the steam sanding apparatus, adopted within the last few years, has been an indispensable factor in bringing these engines again into favour, inasmuch as this apparatus has rendered it possible for them to work satisfactorily on roads, and with trains, which they could not otherwise deal with in all weathers. One of my engines of this type is shown in Plate 39. Its chief features are large cylinders, and piston-valves. The latter are so constructed that they allow any water which may pass over from the boiler to escape freely. Their frictional resistance is small, being only one-sixth of that of the ordinary D slide-valves.

Second Type.—A four-wheel-coupled passenger tender engine with leading bogie is at present the most favoured by a general consensus of opinion, as shown by its adoption in one form or another on nearly every line in the country. It is the most useful engine that can be employed on a railway, because it is suitable for any line with varying gradients and curves, and is a safe and reliable engine. In Plate 39 is shown one of the latest engines I have designed of this type for working the heavier express passenger trains on the Midland Railway.

Third Type.—For goods and mineral traffic the adoption of a six-wheel-coupled tender engine has been almost universal, the diameter of the wheels being slightly greater for fast goods than for heavy mineral trains. In Plate 41 is shown the Midland Railway standard goods locomotive.

Fourth Type.—Suburban passenger traffic is generally worked by four-wheel-coupled tank engines, the coupled wheels in many instances being placed beneath the boiler, and a trailing bogie beneath the coal bunker and tanks. This arrangement, shown in Plate 40, is such as to give a fairly constant weight on the coupled wheels. On the Metropolitan underground line the same class of engine is furnished with condensing apparatus, for use in the tunnels.

Fifth and Sixth Types.—For shunting purposes, six or four-wheel-coupled tank engines, such as are illustrated in Plate 40, are found to be the most suitable.

The leadnig dimensions, weights, steam pressures, &c., of these six types of standard engines now in use on the Midland Railway, are given at the bottom of Table 6 (pages 188–91). The same table clearly illustrates the great progress made in the construction of standard types of locomotives, which, with the exception of George Stephenson's "Rocket" of 1829, have run on the Midland Railway since 1832, or rather were constructed for and worked upon the pioneer lines which have been amalgamated to form this railway. Outline drawings to scale of a few of these engines are shown in Plates 30 and 31. Here George Stephenson's memorable "Rocket" of 1829 is shown side by side with the Leicester and Swannington (now Midland) locomotives of 1832 and 1834, and also with succeeding types of Midland engines, bringing us up to the present time.

The leading dimensions, weights, &c., of some of the latest express engines, built by the locomotive chiefs of some of the large British and Irish Railways, will be found in Table 7 (pages 192–5); and photographs of these are given in Plates 41 to 48.

Locomotive Construction.—Not only has the rolling stock to be made sufficiently strong to bear for a reasonable time the blows and shocks to which it is being constantly subjected, but certain rubbing surfaces, being much exposed to dust and dry friction, are apt to wear rapidly. To check their wear as much as possible, chilled cast-iron horn-blocks and case-hardened wrought-iron axle-boxes, &c., are largely used. The introduction of cast steel in various forms has also proved a great advantage to locomotive engineers, and has materially increased the life of the parts for which it has been used. Run directly into the mould, it forms tough sound castings, suitable for engine and tender wheels, motion plates, cross stays, bogie centres, axle-boxes, axle-box guides, &c. Hammered or rolled, it has almost wholly taken the place of wrought-iron for boiler plates, frame plates, crank and straight axles, connecting-rods, coupling-rods, motion links and pins, piston-rods, and slide-bars. For tires and rails the higher-carbon wrought-steels are used, great toughness being required.

The life of each particular part of a locomotive is of more or less variable duration. Thus of a set of new crank-axles some will run much longer than others; cylinders and valves wear out at rates depending upon their hardness and the work they have to do; boilers groove, corrode, and waste away, according to the amount of the work done and the quality of the water used. Tables 8 to 11 (pages 196–7) show this clearly, for in addition to the average and maximum age of boilers, cylinders, crank-axles, and tires, their mileage is also given. As each type of engine has wheels of different diameter from other types, and the nature of the work varies considerably, the mileage of crank-axles and tires is variable. The durability of boilers and cylinders however is nearly proportional to the mileage worked. As a rule each boiler before being broken up will have had a second copper fire-box put in, and on an average will have had the tubes changed four or five times. The average mileage of new brass tubes is 82,423, of new copper tubes 122,518, and of new red-metal tubes 124,764. Many of the tubes however, before being worn out, are removed in order to admit of an internal examination of the boiler, or for the removal of scale; they are therefore brazed and put in again, thus enabling an additional mileage to be obtained. Owing to the liability of cranks and other moving parts of the engine to fail, in some instances after being at work only a comparatively short time, unceasing vigilance has to be exercised; and each part of the engine is examined not only at stated intervals, but also whenever circumstances may render it advisable. As a further precaution, the parts are so designed that, even if they should give way on the road, the point of rupture, and its nature, shall be such as to render scarcely possible an accident attendant with danger to passengers.

It is no doubt owing, in the first place, to the high steam-pressure now employed and to the steam being used more expansively in larger cylinders, that greater economy and power have been able to be obtained, without any great alterations in the design of the valve-gear. From the result of an elaborate and exhaustive series of experiments made by Mr. Drummond on the Caledonian Railway in 1889, it would appear that in his opinion the most economical results as regard coal and water consumption are for various reasons obtained when the steam pressure is about 175 lbs. per square inch. Although sufficient pressure must be retained at the end of the stroke for creating the necessary draught on the fire, the release and terminal pressures in a well-designed locomotive are low. Indeed the extremes between which the cylinder pressure ranges are for all practical purposes as great as if pressure were not required for blast. The steps by which the steam pressure is reduced from that of the boiler to the atmosphere, and the variations which the vacuum in the smoke-box undergoes, during a complete revolution of the driving wheel in one of my single-wheel engines, are shown in Figs. 14 and 15, Plates 28 and 29. The actual diagrams taken with the indicator are reproduced in Plate 28. Here we have indicator curves showing the changes of steam-chest pressure, cylinder pressure, blast-pipe pressure, and smoke-box vacuum, during each stroke of the piston. The smoke-box vacuum is given in inches of water, as well as in lbs. per square inch. For the purpose of enabling the eye to follow and compare the changes of pressure which take place during a complete revolution of the driving wheel, Plate 29 has been drawn: even at seventy miles per hour the variations of smoke-box vacuum accompanying each jet of exhaust steam are here seen to be as clearly defined as they are at the lower speeds. So low a mean both for the smoke-box vacuum and also for the release pressure has been obtained only with the later designs of engine. Many of the older locomotives give blast pressures much in excess of those here shown, and the mean smoke-box vacuum often rises as high as eight or ten inches of water.

Compounding.—In order to obtain greater degrees of expansion with the link motion, and to reduce the losses resulting from wire-drawing and the condensation resulting from extreme differences of cylinder temperature, many forms of compound locomotives have been built; and some measure of success seems to have attended their working. Every well-considered attempt to increase the economy and power of the locomotive should receive our approbation; but, although compounding has been attended with excellent results in stationary and marine engines, the results of the working of compound locomotives, which I have studied somewhat closely, have not been such as in my opinion would up to the present time have warranted my adopting the compound system. It is only fair to say however that I have not actually tested compound locomotives against my own engines. One of my single-driving-wheel locomotives, running between Nottingham and London, burns per indicated horse-power per hour from 2·9 to 3·1 lbs. of coal with ordinary firing, and uses about 29 lbs. of water per horse-power per hour when the mean indicated horse-power is about 400. This would show rather a high evaporative efficiency; but no doubt the steam supplied is somewhat damp under such conditions, and the water used is therefore not an exact measure of the quantity really evaporated. A non-compound stationary engine, having a large lap and giving an indicator diagram much like that of a locomotive, but working at a boiler pressure of only 100 lbs., consumed 29·6 lbs. of water and 3·38 lbs. of coal per horse-power per hour.

Fuel Consumption.—In Fig. 13, Plate 27, has been plotted the gross consumption of fuel per train mile, together with the percentage of goods and passenger train miles worked. The figure giving the coal consumption includes the coal required for shunting, for bank work, and for light running &c.; and therefore by no means indicates the consumption per train mile of express passenger engines. During the eight years terminating in 1880 the consumption shows a decrease of 9·68 lbs. per train mile, or 17·22 per cent. of the amount of fuel formerly burned; for the year 1880 this represents a saving, after allowing for the increased percentage of passenger train mileage now worked, of £36,990 with coal at 5*s*. 9½*d*. per ton. The larger part of the reduction was effected, notwithstanding the increased loads and accelerated trains, by revising the design of engine and boiler details, and by building locomotives of greater power, and therefore better capable of dealing with the trains they had to work. Cast-iron pistons, with light cast-iron rings sprung over their heads, were substituted for the old heavy brass pistons, which had thick brass rings set up by springs pressing gluts into V shaped slots cut across the rings. New cylinders of larger diameter and having freer ports and exhaust passages were also put in. More attention was paid to the quality of the fuel burned, and the worthless kinds were discontinued. Since 1880 the consumption has been kept low by still further increasing the steam pressure and cylinder diameter, by improving the lubricating devices on passenger and other vehicles, by the adoption of automatic brakes, and by improvements in the roadway &c.

Carriages and Wagons.—From the passengers' point of view, the greatest improvements have been made in the convenience and comfort of passenger coaches. In the early days of railway enterprise most attention was paid to the carriage of minerals and goods; and it does not seem to have been thought that the convenience of railway passengers would have to be considered in the way it now is, for some classes of vehicles in which the public had to travel were not so comfortable as the modern cattle-wagon. But the great immunity from danger, and the rapid transit afforded by railways generally, have caused increasing numbers of passengers to avail themselves of the facilities offered; and the railways have consequently been able to do much for increasing their comfort, not only by improving the speed and punctuality of trains, but also by making the vehicles convenient, comfortable, steady, and even luxurious. In this country the stage-coach type of carriage, having side doors, has held its own to a large extent, owing no doubt to our insular reserve and to the fact that the average passenger does not travel a great distance. On continental lines however, and especially in America, the corridor carriage and the central-passage car have largely superseded the older form on all through trains.

Both in passenger coaches and in vehicles for carrying various descriptions of goods and minerals, modern practice has tended towards a general interchangeability of parts. In the bodies of passenger coaches a certain amount of variability in size, to suit different conditions of traffic, is perhaps necessary; but as passenger trains do not require such constant breaking up and re-marshalling as goods trains, the tendency has been towards building long heavy cars. By placing eight or more wheels under one coach, bogie trucks can be used; and these not only take sharp curves better and give less friction than a long and nearly rigid wheel-base, but they also pass over the rail joints more steadily. With few exceptions in this country the size of wheel used on passenger vehicles is nearly the same on all railways, namely 3 feet 6 inches, the load on the tread being sufficiently small to allow the tire to run a long mileage before wearing thin.

The dimensions, kindly furnished by Mr. T. G. Clayton, of the chief types of passenger vehicles which have been used, or are now in use, on the Midland Railway, are given in Table 13 (pages 198–9); and outline drawings to scale are shown in Plates 32 and 33. In Plate 36 is shown the most recent express dining train running between some of the large towns on the Midland Railway. It consists of six vehicles, and, as will be seen on reference to Table 12 (page 197), weighs in the aggregate 152 tons, and with the locomotive, passengers and luggage, nearly 256 tons; this weight however is liable to be greatly increased at busy times by the addition of extra vehicles.

In the case of goods traffic we have conditions strongly militating against long heavy wagons. In the first place goods and mineral trains have to be broken up and re-marshalled at numerous points, and the wagons have frequently to be moved by horses and also by manual labour. During shunting operations too, the motion of the wagons has to be stopped by the elasticity of spring buffers; and the greater the weight to be dealt with, the slower the shunting operations must be. Such conditions have led to the standard wagon which has four wheels, carrying from eight to twelve tons. In Plates 34 to 36 are given outline sketches of several types of wagons, old and new; and in Table 14 (page 200) will be found their leading dimensions, weights, &c.

Brakes &c.—With increasing speeds the necessity of having better control over trains has made itself felt more and more; and has led to the use of powerful brakes, not only on the locomotives and brake-vans, but also on all the vehicles of passenger trains. Owing largely to the fact that ejectors, capable of raising a high vacuum quickly and economically, can be made of small size and light weight, the automatic vacuum brake has come steadily to the front, being recommended by its simplicity, durability, and efficiency. Improvements are also being made in the lighting and warming of the passenger coaches, the old oil lamps giving place to oil-gas lamps and electric light, and the foot-warmer to an apparatus warming the entire coach by steam or hot water from the locomotive boiler. A promising system of electric lighting for railway trains has been introduced for some years on a number of English and foreign lines. Each coach is fitted with a complete electric-light apparatus, which requires only occasional attention; and therefore the lighting of each carriage is quite independent of its position in the train, or of the system of lighting fitted to others—a highly desirable result to attain. These improvements, it is clear, cannot be obtained without making considerable additions to the gear attached to carriages and locomotives; indeed the fire-box front of a locomotive becomes every year more and more crowded with valves, cocks, and pipes, for steam-sanding gear, injectors, warming apparatus, brakes, and lubricators; while the space between the frames of a coach is a network of brake-gear pipes and couplings; not to mention vacuum and oil-gas reservoirs or electric accumulators underneath the coach body.

Additional Lines, and Signalling.—So restricted have become the conditions under which it is considered advisable to indulge in high speeds, that, wherever the goods traffic is heavy, additional lines have had to be laid down, so that the express trains and other passenger services may not be interfered with, and that the absolute block system may be enforced. A runaway train or inattentive driver must then pass at least two sets of distant and home signals before a collision is possible. The electric telegraph is now the important and necessary means of working and regulating the enormous traffic, which is passed with such ease and regularity on our railways at high speeds. With its aid the absolute block system has been made nearly perfect, and renders the running nearly absolutely safe. Without such mechanical and electrical appliances, the present traffic could not possibly be worked.

In the summary table for the United Kingdom, published in the Board of Trade railway returns, the increase shown from year to year in the length of the lines opened for traffic fails to indicate the magnitude of the extensions which have really been made; for no account is taken of the many lines of rail running side by side between some stations, all roads being treated as though they were only single lines of rail. Thus in 1894 sixteen of the principal railways in England and Wales are returned as having 10,581 miles open for traffic; whereas, if the actual length is taken of the lines of rail shown by the detailed tables to be in use, the figure is raised to 19,045, being an increase of 80 per cent. upon that given in the summary table. Even the higher figure of course does not include siding accommodation.

Permanent Way.—The increasing weights of rails and chairs, the substitution of steel for wrought-iron and cast-iron bridges, and the close attention paid to ballasting, serve to show the extent to which railway engineers are sensible of the necessity for keeping the road well up to the loads it has to carry. Indeed the use of iron rails, owing to the rapidity with which they split and laminate, would now seriously interfere with the working of the line, in consequence of the frequency with which they would have to be relaid. Moreover the improved processes introduced in recent times for the manufacture of steel of all qualities have so reduced its price, that not only does it make the best rail, but it is also the cheapest. Undoubtedly the rail joint is at present the most unsatisfactory portion of the road; for, when the fish plates are well screwed up, the slight movement which takes place between the surfaces leads to wear; and even when lock nuts are used, the joint becomes loose unless it is periodically screwed up. The use of longitudinal sleepers by no means obviates these difficulties; for as the sleepers are elastic, the rail ends hammer them when the load passes over, and they have frequently to be packed up. Plates 37 and 38, kindly furnished by Mr. J. A. McDonald, Chief Civil Engineer of the Midland Railway, give a good idea of the improvements which have been made from time to time in the size, weight, and shape of the chairs and rails used on this railway, or on lines which now form part of the system. Here the section of the old wrought-iron fish-belly rail, weighing only 35 lbs. per yard and only 15 feet long, is shown side by side with the later steel rails, which for 1896 weigh 100 lbs. per yard and measure 36 feet in length. The danger of points and crossings has been largely diminished by the use of locking devices, and by fixing facing points at junctions only, or only where absolutely necessary.

Gauge.—My ideal gauge for a railway is 5 feet 3 inches. How many of the difficulties experienced by locomotive superintendents and mechanical engineers would have been avoided, had the 4 ft. 8½ ins. gauge been superseded years ago by the 5 ft. 3 ins. gauge. The crowding of machinery into the confined space between the frames limits the boiler diameter when the wheels are large, cramps the firebox width, and unduly reduces the dimensions of crank bearing surfaces and webs. All these obstacles would have disappeared, and many things which are now so difficult would have been easy of accomplishment, had the gauge been made somewhat broader.

The progress of railway engineering in the past having been so great, our thoughts naturally turn to the future; and, although prophecy is proverbially risky, I cannot help thinking that the signs of the times point to electricity as likely to prove a most important agent in the hands of future railway mechanical engineers.

It has been my endeavour in this address to show how largely and how regularly our railway traffic has increased, and how great has been the prosperity of this country since rapid means of transport were rendered possible by the invention of the locomotive engine. Our retrospect deals in a great measure with the sixty years during which Her Most Gracious Majesty Queen Victoria has so beneficently reigned over us, and brings us to the year set apart by a grateful people for her jubilee. Such a retrospect cannot fail to give confidence in the future, because the conditions affecting both railway and marine engineering, which have so greatly promoted progress in the past, are still dominant, and these two branches of locomotion have brought all parts of the world within comparatively easy reach of one another, thus enabling the "old country" to profit by the growth of the more distant portions of the empire, as well as by the prosperity of neighbouring nations.

TABLE 1.

Passengers (exclusive of season-ticket holders) and Goods carried by the Railways of the United Kingdom in 1878 *and* 1896.

Year	1878	1896	Increase.	
			Absolute.	Per cent.
Number of Passengers .	565,024,455	980,339,433	415,314,978	73·5
Mileage of Passenger Trains . . .	113,184,252	193,661,054	80,476,802	71·1
Tonnage of Goods and Minerals . . .	206,735,856	356,468,009	149,732,153	72·4
Mileage of Goods and Mineral Trains . .	106,034,197	157,740,487	51,706,290	48·7

TABLE 2.

Midland Railway Locomotive Power. Average separate Costs per train mile for Passenger, Goods, and Mineral Trains in March and September 1892. (*See Plate* 24.)

Class of Train	Passenger.	Goods.	Mineral.
	Pence.	Pence.	Pence.
Running Expenses.			
Wages of Drivers and Firemen .	1·38	2·52	4·19
,, Cleaners, Coalmen &c. .	0·49	0·71	0·93
Water	0·20	0·30	0·36
Oil and Stores	0·27	0·32	0·33
Coal and Coke	1·77	2·61	3·04
Totals of Running Expenses .	—— 4·11	—— 6·46	—— 8·85
Repairs and Renewals.			
Wages	1·30	1·30	1·30
Materials	1·26	1·26	1·26
Totals of Repairs and Renewals	—— 2·56	—— 2·56	—— 2·56
Salaries and Sundries.			
Salaries	0·17	0·17	0·17
Turntables and Buildings . .	0·02	0·02	0·02
Gas	0·08	0·08	0·08
Totals of Salaries and Sundries	—— 0·27	—— 0·27	—— 0·27
Total Costs per train mile . .	6·94	9·29	11·68

TABLE 3 (*continued to page* 177).

Midland Railway TOTAL *Locomotive Expenditure &c.*

during twenty-four years 1873–96.

See Plate 25.

	Particulars of Expenditure &c.		1873	1874	1875
	Running Expenses.		£	£	£
a	Wages	Drivers and Firemen	190,077	215,040	242,520
b		Cleaners, Coalmen &c.	64,211	69,310	68,846
c	Water		18,750	20,556	20,831
d	Oil and Stores		37,634	32,633	33,095
e	Coal and Coke		364,835	366,763	287,428
f	Total Running Expenses		£675,507	£704,302	£652,720
g	*Repairs and Renewals.*	Wages	107,557	119,962	136,620
h		Materials	129,020	150,318	166,428
i	Total Repairs and Renewals		£236,577	£270,280	£303,048
j	Salaries		16,496	18,022	19,361
k	Turntables and Buildings		2,086	1,027	1,867
l	Gas		4,936	5,948	6,353
m	Gross Expenditure		£935,602	£999,579	£983,349
	Deduct engine power for ballasting & working on other railways &c.		56,047	63,268	77,026
n	Net Expenditure		£879,555	£936,311	£906,323
o	Tons of Coal and Coke consumed		505,763	508,590	536,733
p	Miles of Line worked		1,335½	1,388¼	1,491¾
q	Train Mileage	Passenger	6,943,578	7,198,709	7,855,520
r		Goods and Mineral	12,867,818	13,635,333	14,659,714
s		Total	19,811,396	20,834,042	22,515,234
t		Net	19,488,685	20,424,166	21,884,850
u	Engine Mileage, total		24,972,261	26,910,264	29,523,671
v	Average number of Engines	in regular stock	1,012	1,075	1,153
w		in duplicate stock	44	46	54
x		in steam daily for piloting, shunting, and ballasting; producing no train mileage, but expenses charged to locomotive power	180	200	219
y	Number of Staff		5,773	6,102	6,693
z	Traffic Receipts		£5,311,433	£5,602,498	£5,956,374

(*continued on next page*) TABLE 3.

Midland Railway TOTAL *Locomotive Expenditure &c.*

during twenty-four years 1873–96.

See Plate 25.

1876	1877	1878	1879	1880	1881	
£	£	£	£	£	£	
257,138	264,095	268,647	287,496	298,668	322,340	*a*
69,474	72,151	73,218	74,440	80,428	84,341	*b*
21,002	21,827	21,303	21,627	24,182	27,566	*c*
38,338	41,398	42,747	41,245	44,788	49,139	*d*
255,909	215,927	183,135	177,301	177,743	198,476	*e*
£641,861	£615,398	£589,050	£602,109	£625,809	£681,862	*f*
145,750	153,978	159,905	155,956	161,294	168,234	*g*
177,151	167,920	163,354	160,470	164,813	176,914	*h*
£322,901	£321,898	£323,259	£316,426	£326,107	£345,148	*i*
20,769	21,527	21,779	21,411	22,013	22,200	*j*
2,666	3,225	3,704	3,228	4,259	3,327	*k*
6,744	7,126	7,311	7,444	7,401	8,210	*l*
£994,941	£969,174	£945,103	£950,618	£985,589	£1,060,747	*m*
88,035	72,314	61,592	64,047	68,959	82,793	
£906,906	£896,860	£883,511	£886,571	£916,630	£977,954	*n*
556,109	560,566	557,025	594,817	613,767	668,233	*o*
1,582	1,600¾	1,620½	1,691¾	1,728¼	1,769¼	*p*
8,858,034	9,355,989	9,620,176	10,032,958	11,582,045	12,590,331	*q*
14,793,512	15,382,328	16,001,400	17,064,777	17,976,413	18,993,429	*r*
23,651,546	24,738,317	25,621,576	27,097,735	29,558,458	31,583,760	*s*
22,956,060	24,018,169	24,892,499	26,331,264	28,681,838	30,527,472	*t*
31,342,420	32,436,177	33,323,592	35,330,057	38,214,730	40,694,483	*u*
1,259	1,334	1,367	1,405	1,443	1,505	*v*
56	58	59	60	60	60	*w*
257	270	267	274	283	295	*x*
7,212	7,628	7,934	8,251	8,745	9,122	*y*
£6,090,010	£6,231,931	£6,313,684	£6,398,039	£6,659,902	£6,857,901	*z*

TABLE 3 (*continued from preceding page*).

Midland Railway TOTAL *Locomotive Expenditure &c.*

during twenty-four years 1873–96.

See Plate 25.

	Particulars of Expenditure &c.	1882	1883
	Running Expenses.	£	£
a	Wages { Drivers and Firemen . . .	324,904	341,453
b	Wages { Cleaners, Coalmen &c. . .	85,784	89,192
c	Water	25,093	28,802
d	Oil and Stores	52,065	57,474
e	Coal and Coke	205,538	233,462
f	Total Running Expenses	£693,384	£750,383
g	*Repairs and Renewals.* { Wages . .	164,063	172,037
h	*Repairs and Renewals.* { Materials . .	179,774	188,704
i	Total Repairs and Renewals	£343,837	£360,741
j	Salaries	22,873	23,737
k	Turntables and Buildings . . .	2,307	2,898
l	Gas	8,115	8,111
m	Gross Expenditure	£1,070,516	£1,145,870
	Deduct engine power for ballasting, and for working on other railways &c. .	75,729	79,997
n	Net Expenditure	£994,787	£1,065,873
o	Tons of Coal and Coke consumed . .	678,600	723,796
p	Miles of Line worked	1,779	1,791
q	Train Mileage { Passenger	12,798,345	13,105,400
r	Train Mileage { Goods and Mineral . . .	19,264,391	19,981,855
s	Train Mileage { Total	32,062,736	33,087,255
t	Train Mileage { Net	31,062,433	32,030,777
u	Engine Mileage, total	41,330,281	43,124,207
v	Average number of Engines { in regular stock . . .	1,563	1,604
w	Average number of Engines { in duplicate stock . . .	60	66
x	Average number of Engines { in steam daily for piloting, shunting, and ballasting; producing no train mileage, but expenses charged to locomotive power	300	313
y	Number of Staff	9,221	9,525
z	Traffic Receipts	£7,079,444	£7,322,000

(*continued on next page*) TABLE 3.

Midland Railway TOTAL *Locomotive Expenditure &c.*

during twenty-four years 1873–96.

See Plate 25.

1884	1885	1886	1887	1888	1889	
£	£	£	£	£	£	
343,199	348,607	346,102	357,002	366,138	399,938	*a*
92,354	94,699	95,452	94,539	94,348	99,504	*b*
26,870	24,560	25,947	26,676	28,807	31,060	*c*
49,194	42,301	36,696	34,427	39,129	43,121	*d*
242,908	234,700	218,808	219,535	232,642	290,438	*e*
£754,525	£744,867	£723,005	£732,179	£761,064	£864,061	*f*
172,348	170,822	158,110	172,704	186,689	192,145	*g*
178,180	166,055	144,793	148,214	164,164	195,358	*h*
£350,528	£336,877	£302,903	£320,918	£350,853	£387,503	*i*
24,112	24,232	24,350	25,004	24,987	26,164	*j*
3,633	2,486	2,180	2,076	2,470	2,815	*k*
8,264	8,497	8,842	8,652	9,592	9,858	*l*
£1,141,062	£1,116,959	£1,061,280	£1,088,829	£1,148,966	£1,290,401	*m*
80,342	78,538	73,249	72,370	78,948	90,587	
£1,060,720	£1,038,421	£988,031	£1,016,459	£1,070,018	£1,199,814	*n*
711,601	719,281	701,204	726,006	762,009	821,739	*o*
1,841½	1,852	1,855¾	1,874¾	1,972¾	1,991¾	*p*
13,561,519	13,867,257	14,031,733	14,103,293	14,562,291	15,415,624	*q*
19,700,210	19,706,141	19,265,817	19,355,526	20,596,091	22,222,398	*r*
33,261,729	33,573,398	33,297.550	33,458,819	35,158,382	37,638,022	*s*
32,145,949	32,431,157	32,160,984	32,297,810	33,953,205	36,145,320	*t*
43,201,974	43,657,427	43,379,326	43,582,687	45,948,108	49,177,254	*u*
1,663	1,714	1,749	1,781	1,808	1,833	*v*
74	73	70	70	72	73	*w*
313	318	317	320	345	362	*x*
9,607	9,853	9,655	9,734	10,201	10,958	*y*
£7,329,734	£7,306,849	£7,166,119	£7,252,856	£7,567,659	£8,153.344	*z*

TABLE 3 (*continued from preceding page*).

Midland Railway TOTAL *Locomotive Expenditure &c.*

during twenty-four years 1873–96.

See Plate 25.

	Particulars of Expenditure &c.	1890	1891
	Running Expenses.	£	£
a	Wages { Drivers and Firemen	428,446	479,612
b	Wages { Cleaners, Coalmen &c.	104,514	112,896
c	Water	33,416	35,946
d	Oil and Stores	50,785	55,479
e	Coal and Coke	395,701	438,678
f	Total Running Expenses	£1,012,862	£1,122,611
g	*Repairs and Renewals.* { Wages	204,404	216,072
h	*Repairs and Renewals.* { Materials	222,027	233,687
i	Total Repairs and Renewals	£426,431	£449,759
j	Salaries	26,201	28,583
k	Turntables and Buildings	2,691	3,237
l	Gas	11,215	12,985
m	Gross Expenditure	£1,479,400	£1,617,175
	Deduct engine power for ballasting, and for working on other railways &c.	108,910	119,641
n	Net Expenditure	£1,370,490	£1,497,534
o	Tons of Coal and Coke consumed	868,106	916,348
p	Miles of Line worked	1,942	1,942¾
q	Train Mileage { Passenger	15,404,090	16,117,317
r	Train Mileage { Goods and Mineral	23,659,746	24,784,988
	Train Mileage { Total	39,063,836	40,902,305
t	Train Mileage { Net	37,543,884	39,343,049
u	Engine Mileage, total	51,698,408	55,290,560
v	Average number of Engines { in regular stock	1,885	1,973
w	Average number of Engines { in duplicate stock	78	91
x	Average number of Engines { in steam daily for piloting, shunting, and ballasting; producing no train mileage, but expenses charged to locomotive power	403	473
y	Number of Staff	11,574	12,538
z	Traffic Receipts	£8,613,173	£9,039,835

(*concluded from page* 172) TABLE 3.

Midland Railway TOTAL *Locomotive Expenditure &c.*

during twenty-four years 1873–96.

See Plate 25.

1892	1893	1894	1895	1896	AVERAGE	
£	£	£	£	£	£	
498,046	457,061	501,443	520,234	549,026	358,635	*a*
120,749	122,389	130,905	135,837	136,554	94,422	*b*
38,451	38,037	39,000	41,963	43,526	28,575	*c*
54,372	48,819	49,964	49,853	51,520	44,842	*d*
430,410	449,816	394,851	379,668	355,601	289,595	*e*
£1,142,028	£1,116,122	£1,116,163	£1,127,555	£1,136,227	£816,069	*f*
225,406	210,948	242,408	238,023	253,794	178,718	*g*
217,172	180,452	205,250	200,424	209,170	178,742	*h*
£442,578	£391,400	£447,658	£438,447	£462,964	£357,460	*i*
29,294	28,854	29,461	29,202	29,851	24,187	*j*
3,492	3,111	3,152	3,577	3,148	2,861	*k*
13,448	13,808	17,078	17,954	18,946	9,868	*l*
£1,630,840	£1,553,295	£1,613,512	£1,616,735	£1,651,136	£1,210,445	*m*
127,878	126,862	127,566	108,221	118,193	87,546	
£1,502,962	£1,426,433	£1,485,946	£1,508,514	£1,532,943	£1,122,899	*n*
934,549	855,929	959,977	974,141	1,014,454	727,889	*o*
1,947	1,998	1,987	2,016	1,974¾	1,790½	*p*
16,477,705	16,039,875	16,223,306	16,339,648	16,838,401	12,871,798	*q*
24,999,232	21,995,880	24,405,099	24,322,072	25,095,410	19,613,732	*r*
41,476,937	38,035,755	40,628,405	40,661,720	41,933,811	32,485,530	*s*
39,856,974	36,480,466	38,890,931	39,079,797	40,171,198	31,366,622	*t*
56,646,625	52,222,978	55,610,161	55,743,750	57,666,216	42,959,484	*u*
2,096	2,195	2,222	2,240	2,272	1,673	*v*
112	131	147	162	167	81	*w*
496	467	499	490	504	340	*x*
13,157	13,165	13,823	14,151	14,669	9,970	*y*
£9,079,305	£8,235,661	£8,956,466	£8,993,396	£9,446,986	£7,373,525	*z*

TABLE 4 (*continued to page* 183).

Midland Railway Locomotive Expenditure &c. PER TRAIN MILE *during twenty-four years* 1873–96.

See Plate 26.

	Particulars of Expenditure &c.	1873	1874	1875
	Running Expenses.	Pence.	Pence.	Pence.
a	Wages: Drivers and Firemen . .	2·302	2·477	2·585
b	Wages: Cleaners, Coalmen &c. .	0·778	0·798	0·734
c	Water	0·227	0·237	0·222
d	Oil and Stores	0·456	0·376	0·353
e	Coal and Coke	4·420	4·225	3·064
f	Total Running Expenses	8·183	8·113	6·958
g	*Repairs and Renewals.* Wages .	1·303	1·382	1·456
h	*Repairs and Renewals.* Materials .	1·563	1·731	1·774
i	Total Repairs and Renewals	2·866	3·113	3·230
j	Salaries	0·200	0·208	0·206
k	Turntables and Buildings . .	0·025	0·012	0·020
l	Gas	0·060	0·069	0·068
m	Gross Expenditure	11·334	11·515	10·482
n	Net Expenditure, after deducting engine power for ballasting, and for working on other railways &c.	10·832	11·002	9·939
o	Coal and Coke: lbs. per train mile	57·185	54·682	53·399
	Coal and Coke: average price per ton	14*s.* 5*d.*	14*s.* 5*d.*	10*s.* 8½*d.*
	Train Mileage: Passenger per cent.	35·0	34·6	34·9
	Train Mileage: Goods and Mineral, per cent.	65·0	65·4	65·1
	Train Mileage: per Engine in regular stock	19,576	19,381	19,528
	Staff per Engine in regular stock	5·705	5·676	5·805
	Traffic Receipts: per Engine in regular stock	£5,248	£5,212	£5,166
z	Traffic Receipts: per train mile . . .	5*s.* 4¼*d.*	5*s.* 4½*d.*	5*s.* 5¼*d.*

(*continued on next page*) TABLE 4.

Midland Railway Locomotive Expenditure &c. PER TRAIN MILE *during twenty-four years* 1873–96.

See Plate 26.

1876	1877	1878	1879	1880	1881	
Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	
2·609	2·562	2·516	2·546	2·425	2·449	*a*
0·705	0·700	0·686	0·659	0·653	0·641	*b*
0·213	0·212	0·200	0·192	0·196	0·210	*c*
0·389	0·401	0·400	0·365	0·364	0·373	*d*
2·597	2·095	1·716	1·571	1·443	1·508	*e*
6·513	5·970	5·518	5·333	5·081	5·181	*f*
1·479	1·494	1·498	1·381	1·310	1·279	*g*
1·798	1·629	1·530	1·421	1·338	1·344	*h*
3·277	3·123	3·028	2·802	2·648	2·623	*i*
0·211	0·209	0·204	0·190	0·179	0·169	*j*
0·027	0·031	0·035	0 028	0·034	0·025	*k*
0·068	0·069	0·068	0·066	0·060	0·062	*l*
10·096	9·402	8·853	8·419	8·002	8·060	*m*
9·481	8·962	8·518	8·081	7·670	7·688	*n*
52·668	50·758	48·699	49·170	46·513	47·393	*o*
9*s.* 2½*d.*	7*s.* 8½*d.*	6*s.* 7*d.*	5*s.* 11½*d.*	5*s.* 9½*d.*	5*s.* 11¼*d.*	
37·5	37·8	37·5	37·0	39·2	39·9	
62·5	62·2	62·5	63·0	60·8	60·1	
18,786	18,544	18,743	19,287	20,484	20,986	
5·728	5·718	5·804	5·873	6·060	6·061	
£4,837	£4,672	£4,619	£4,554	£4,615	£4,557	
5*s.* 3¾*d.*	5*s.* 2¼*d.*	5*s.* 0¾*d.*	4*s.* 10¼*d.*	4*s.* 7¾*d.*	4*s.* 6*d.*	*z*

TABLE 4 (*continued from preceding page*).

Midland Railway Locomotive Expenditure &c. PER TRAIN MILE *during twenty-four years* 1873–96.

See Plate 26.

	Particulars of Expenditure &c.		1882	1883
	Running Expenses.		Pence.	Pence.
a	Wages	Drivers and Firemen	2·432	2·477
b		Cleaners, Coalmen &c.	0·642	0·647
c	Water		0·188	0·209
d	Oil and Stores		0·390	0·417
e	Coal and Coke		1·538	1·693
f		Total Running Expenses	5·190	5·443
g	*Repairs and Renewals.*	Wages	1·228	1·248
h		Materials	1·346	1·369
i		Total Repairs and Renewals	2·574	2·617
j	Salaries		0·171	0·172
k	Turntables and Buildings		0·017	0·021
l	Gas		0·061	0·059
m	Gross Expenditure		8·013	8·312
n	Net Expenditure, after deducting engine power for ballasting, and for working on other railways &c.		7·686	7·986
o	Coal and Coke	lbs. per train mile	47·409	49·001
		average price per ton	6*s.* 0¾*d.*	6*s.* 5½*d.*
	Train Mileage	Passenger . per cent.	39·9	39·6
		Goods and Mineral . per cent.	60·1	60·4
		per Engine in regular stock	20,514	20,628
	Staff per Engine in regular stock		5·900	5·938
	Traffic Receipts	per Engine in regular stock	£4,529	£4,565
z		per train mile	4*s.* 6¾*d.*	4*s.* 6¾*d.*

(continued on next page) TABLE 4.

Midland Railway Locomotive Expenditure &c. PER TRAIN MILE *during twenty-four years* 1873–96.

See Plate 26.

1884	1885	1886	1887	1888	1889	
Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	
2·476	2·492	2·495	2·561	2·499	2·550	*a*
0·666	0·677	0·688	0·678	0·644	0·634	*b*
0·194	0·176	0·187	0·191	0·197	0·198	*c*
0·355	0·302	0·264	0·247	0·267	0·275	*d*
1·753	1·678	1·577	1·575	1·588	1·852	*e*
5·444	5·325	5·211	5·252	5·195	5·509	*f*
1·243	1·221	1·139	1·239	1·274	1·225	*g*
1·286	1·187	1·044	1·063	1·121	1·246	*h*
2·529	2·408	2·183	2·302	2·395	2·471	*i*
0·174	0·173	0·175	0·179	0·171	0·167	*j*
0·026	0·018	0·016	0·015	0·017	0·018	*k*
0·060	0·061	0·064	0·062	0·065	0·063	*l*
8·233	7·985	7·649	7·810	7·843	8·228	*m*
7·919	7·685	7·373	7·553	7·563	7·967	*n*
47·923	47·990	47·172	48·605	48·549	48·905	*o*
6*s.* 10*d.*	6*s.* 6¼*d.*	6*s.* 3*d.*	6*s.* 0½*d.*	6*s.* 1¼*d.*	7*s.* 0¾*d.*	
40·8	41·3	42·1	42·2	41·4	41·0	
59·2	58·7	57·9	57·8	58·6	59·0	
20,001	19,588	19,038	18,787	19,446	20,534	
5·777	5·749	5·520	5·465	5·642	5·978	
£4,408	£4,263	£4,097	£4,072	£4,186	£4,448	
4*s.* 6¾*d.*	4*s.* 6*d.*	4*s.* 5½*d.*	4*s.* 6*d.*	4*s.* 5½*d.*	4*s.* 6¼*d.*	*z*

TABLE 4 (*continued from preceding page*).

Midland Railway Locomotive Expenditure &c. PER TRAIN MILE *during twenty-four years* 1873–96.

See Plate 26.

	Particulars of Expenditure &c.		1890	1891
		Running Expenses.	Pence.	Pence.
a	Wages	Drivers and Firemen . . .	2·632	2·814
b		Cleaners, Coalmen &c. . . .	0·642	0·662
c	Water		0·206	0·211
d	Oil and Stores		0·312	0·326
e	Coal and Coke		2·431	2·574
f		Total Running Expenses	6·223	6·587
g	*Repairs and Renewals.*	Wages . . .	1·256	1·268
h		Materials . .	1·364	1·371
i		Total Repairs and Renewals	2·620	2·639
j	Salaries		0·161	0·168
k	Turntables and Buildings		0·016	0·019
l	Gas		0·069	0·076
m	Gross Expenditure		9·089	9·489
n	Net Expenditure, after deducting engine power for ballasting, and for working on other railways &c. . .		8·761	9·135
o	Coal and Coke	lbs. per train mile . . .	49·779	50·183
		average price per ton . .	9*s.* 1½*d.*	9*s.* 7*d.*
	Train Mileage	Passenger . . . per cent.	39·4	39·4
		Goods and Mineral . per cent.	60·6	60·6
		per Engine in regular stock . .	20,724	20,731
	Staff per Engine in regular stock . . .		6·140	6·355
	Traffic Receipts	per Engine in regular stock . .	£4,569	£4,582
z		per train mile	4*s.* 7*d.*	4*s.* 7¼*d.*

(concluded from page 178) TABLE 4.

Midland Railway Locomotive Expenditure &c. PER TRAIN MILE

during twenty-four years 1873–96.

See Plate 26.

1892	1893	1894	1895	1896	**AVERAGE**	
Pence.	Pence.	Pence.	Pence.	Pence.	Pence.	
2·882	2·884	2·962	3·070	3·142	2·650	*a*
0·699	0·772	0·773	0·802	0·782	0·698	*b*
0·222	0·240	0·230	0·248	0·249	0·211	*c*
0·315	0·308	0·295	0·294	0·295	0·331	*d*
2·490	2·838	2·333	2·241	2·035	2·139	*e*
6·608	7·042	6·593	6·655	6·503	6·029	*f*
1·304	1·331	1·432	1·405	1·453	1·320	*g*
1·257	1·139	1·212	1·183	1·197	1·321	*h*
2·561	2·470	2·644	2·588	2·650	2·641	*i*
0·170	0·182	0·174	0·173	0·171	0·179	*j*
0·020	0·020	0·019	0·021	0·018	0·021	*k*
0·078	0·087	0·101	0·106	0·108	0·073	*l*
9·437	9·801	9·531	9·543	9·450	8·943	*m*
9·050	9·384	9·170	9·264	9·158	8·592	*n*
50·471	50·407	52·927	53·664	54·190	50·191	*o*
9*s*. 2½*d*.	10*s*. 6¼*d*.	8*s*. 2¾*d*.	7*s*. 9½*d*.	7*s*. 0¼*d*.	7*s*. 11½*d*.	
39·7	42·2	39·9	40·2	40·2	39·6	
60·3	57·8	60·1	59·8	59·8	60·4	
19,789	17,328	18,285	18,153	18,457	19,418	
6·277	5·998	6·221	6·317	6·456	5·959	
£4,332	£3,752	£4,031	£4,015	£4,158	£4,407	
4*s*. 6¾*d*.	4*s*. 6¼*d*.	4*s*. 7¼*d*.	4*s*. 7¼*d*.	4*s*. 8½*d*.	4*s*. 6½*d*.	*z*

TABLE 5 (*continued to page* 187).

Midland Railway maximum booked Speeds in miles per hour for the month of July in forty-three years 1855–97.

Run without stop between	Miles	1855	1856	1857	1858	1859	1860	1861
Derby and Burton . . .	11	36·7	36·7	36·7	36·7	36·7	36·7	...
Leicester and Loughborough	12½	35·7	35·7	39·5	41·7	...	44·1	44·1
Masborough and Cudworth .	13¼	36·2	36·2	...	...	...	...	...
Leeds and Bradford . . .	13¾	...	...	...	...	...	...	...
Bedford and Wellingborough	15½	...	...	...	38·8	42·2	42·2	42·2
Loughborough and Derby .	17½	37·5	...	...	...	38·9	37·5	37·5
Sheffield and Cudworth . .	18¾	...	...	...	...	...	...	...
Leicester and Trent . . .	20¾	...	43·0	41·5	...	...	...	...
Masborough and Normanton	23¼	42·3	42·3	42·3	42·3	42·3	41·0	42·3
Derby and Chesterfield . .	24	42·3	42·3	42·3	42·3	42·3	48·0	48·0
Leeds and Skipton . . .	26	...	...	...	...	...	...	...
Sheffield and Normanton .	28¾	...	...	...	...	...	...	...
Leicester and Derby . . .	30	...	...	...	...	...	...	...
Derby and Sheffield . . .	36¼	...	...	...	...	...	...	...
Sheffield and Leeds . . .	39½	...	...	...	...	...	...	...
Nottingham and Sheffield .	40½	...	...	...	...	...	...	...
Derby and Birmingham . .	42¼	...	...	...	...	...	...	...
Marple and Derby . . .	48¾	...	...	...	...	...	...	...
Bedford and Leicester . .	49½	...	...	...	...	...	...	...
London and Bedford . . .	49¾	...	...	...	...	...	...	...
Kettering and Nottingham .	51¾	...	...	...	...	...	...	...
Derby and Manchester . .	62¾	...	...	...	...	...	...	...
London and Kettering . .	72¼	...	...	...	...	...	...	...
Hellifield and Carlisle . .	76½	...	...	...	...	...	...	...
Skipton and Carlisle . . .	87¾	...	...	...	...	...	...	...
London and Leicester . .	99¼	...	...	...	...	...	...	...
London and Nottingham .	124	...	...	...	...	...	...	...
Average Speed in each year		38·4	39·3	40·4	40·3	40·5	41·6	42·8

(continued on next page) TABLE 5.

Midland Railway maximum booked Speeds in miles per hour for the month of July in forty-three years 1855–97.

1862	1863	1864	1865	1866	1867	1868	1869	1870	1871	1872	1873	1874	1875
41·2	41·2	36·7	36·7	41·2	41·2	38·8	38·8	38·8	36·6	38·8	36·6	36·6	36·6
39·5	41·7	39·5	39·5	39·5	44·2	46·9	41·7	41·7	41·7	41·7	41·7	41·7	44·1
39·7	31·8	31·8	31·8	31·8	31·8	37·9	37·9	39·8	34·6	34·6	41·8	39·8	41·8
…	…	…	…	33·0	33·0	33·0	33·0	41·2	41·2	41·2	41·2	41·2	41·2
42·2	38·8	38·8	38·8	40·5	40·5	44·3	44·3	44·3	44·3	44·3	44·3	44·3	44·3
…	…	…	…	…	32·8	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	41·7	41·7	43·3	43·3	43·3	43·3
…	44·4	46·0	46·0	46·0	46·0	46·0	44·4	44·4	44·4	44·4	44·4	44·4	44·4
41·0	41·0	39·9	39·9	42·3	45·0	48·2	45·0	45·0	45·0	45·0	45·0	45·0	45·0
42·3	42·3	42·3	42·3	43·7	43·7	43·7	41·2	42·3	42·3	41·2	41·2	42·3	42·3
43·3	43·3	39·0	39·0	34·7	34·7	37·2	39·0	35·5	36·3	38·1	40·0	40·0	40·0
…	…	…	…	…	…	…	…	43·0	43·0	43·0	…	43·0	44·3
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	41·5	…	…	45·6	45·6
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	41·2
…	44·3	44·3	44·3	45·7	45·7	45·0	45·0	45·0	45·0	45·0	44·3	45·7	46·5
…	…	…	…	…	…	…	42·4	42·4	…	…	…	…	46·7
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…	…	…	…
41·3	40·9	39·8	39·8	39·8	39·9	42·1	41·1	41·9	41·3	41·7	42·1	42·5	43·1

TABLE 5 (*continued from preceding page*).

Midland Railway maximum booked Speeds in miles per hour for the month of July in forty-three years 1855–97.

Run without stop between	1876	1877	1878	1879	1880	1881	1882	1883
Derby and Burton . . .	38·8	38·8	38·8	38·8	38·8	38·8	38·8	44·0
Leicester and Loughborough	44·1	44·1	44·1	44·1	44·1	44·1	44·1	44·1
Masborough and Cudworth	41·8	41·8	41·8	44·2	44·2	44·2	44·2	44·2
Leeds and Bradford . . .	41·2	41·2	41·2	41·2	41·2	41·2	41·2	41·2
Bedford and Wellingborough	42·3	42·3	42·3	42·3	44·3	44·3	44·3	44·3
Loughborough and Derby .	42·0	42·0	43·8	43·8	43·8	43·8	43·8	43·8
Sheffield and Cudworth . .	43·3	45·0	45·0	43·3	43·3	43·3	43·3	43·3
Leicester and Trent . . .	44·4	44·4	46·2	47·9	46·2	46·2	46·2	46·2
Masborough and Normanton	42·2	42·2	42·2	42·2	42·2	42·2	42·2	42·2
Derby and Chesterfield . .	43·6	43·6	43·6	43·6	43·6	43·6	43·6	43·6
Leeds and Skipton . . .	41·0	41·0	39·0	39·0	...	...	...	...
Sheffield and Normanton .	44·3	46·6	46·6	46·6	46·6	46·6	46·6	46·6
Leicester and Derby . .	41·8	45·0	46·1	47·3	47·3	47·3	47·3	47·3
Derby and Sheffield . .	42·7	42·7	42·7	42·7	45·3	45·3	45·3	45·3
Sheffield and Leeds . . .	46·5	46·5	46·5	46·5	48·3	47·4	47·4	47·4
Nottingham and Sheffield .	...	...	...	...	45·8	45·0	45·0	45·0
Derby and Birmingham .	...	...	...	...	...	...	...	...
Marple and Derby . . .	41·2	41·2	41·2	41·2	43·0	43·0	43·0	43·7
Bedford and Leicester . .	47·2	47·2	47·2	47·2	47·2	49·5	49·5	49·5
London and Bedford . .	47·4	47·4	47·4	47·4	47·4	49·8	49·8	49·8
Kettering and Nottingham .	...	...	...	...	48·5	49·3	49·3	49·3
Derby and Manchester . .	...	...	...	...	...	...	...	...
London and Kettering . .	...	...	...	...	48·7	49·3	49·3	49·3
Hellifield and Carlisle . .	...	...	...	...	...	44·8	44·8	44·8
Skipton and Carlisle . .	43·9	45·7	45·7	45·7	45·7	45·7	45·7	45·7
London and Leicester . .	...	...	...	...	46·9	46·9	46·9	46·9
London and Nottingham .	...	...	...	...	...	...	...	...
Average Speed in each year	43·1	43·6	43·7	43·9	45·1	45·3	45·3	45·5

(*concluded from page* 184) TABLE 5.

Midland Railway maximum booked Speeds in miles per hour for the month of July in forty-three years 1855–97.

1884	1885	1886	1887	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897
44·0	44·0	44·0	44·0	44·0	44·0	44·0	44·0	44·0	44·0	44·0	44·0	47·2	47·2
44·1	44·1	44·1	44·1	44·1	44·1	44·1	46·8	46·8	46·8	46·8	46·8	46·8	46·8
44·2	44·2	46·7	44·2	46·8	46·8	49·7	49·7	49·7	49·7	49·7	49·7	49·7	49·7
41·2	43·4	43·4	43·4	43·4	43·4	43·4	43·4	43·4	41·2	43·4	43·4	43·4	43·4
44·3	42·3	42·3	44·3	42·3	42·3	42·3	48·9	48·9	48·9	48·9	48·9	48·9	48·9
43·8	43·8	45·7	45·7	45·7	45·7	45·7	47·8	45·7	45·7	45·7	47·8	45·7	45·7
43·3	43·3	46·8	46·8	46·8	46·8	46·8	46·8	46·8	46·8	46·8	46·8	46·8	46·8
46·2	46·2	46·2	46·2	46·2	46·2	51·9	47·9	47·9	47·9	47·9	49·8	49·8	49·8
42·2	42·2	42·2	42·2	42·2	42·2	42·2	49·8	45·0	51·7	51·7	51·7	51·7	51·7
43·6	41·2	41·2	41·2	41·2	48·0	48·0	48·0	48·0	48·0	48·0	46·4	46·4	48·0
...	...	...	44·6	44·6	44·6	45·9	44·6	44·6	44·6	47·3	45·9	47·3	47·3
46·6	47·9	47·9	47·9	47·9	47·9	47·9	49·3	49·3	49·3	49·3	50·7	50·7	49·3
48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6	48·6
45·3	45·3	45·3	46·3	46·3	46·3	49·4	46·3	47·3	46·3	46·3	46·3	46·3	46·3
47·4	47·4	47·4	48·3	48·3	48·3	48·3	47·4	47·4	47·4	49·3	47·4	47·4	47·4
46·8	46·8	46·8	46·8	46·8	47·7	47·7	47·7	47·7	46·7	46·7	46·7	46·7	46·7
...	...	...	...	...	46·9	46·9	46·9	46·9	46·9	46·9	46·9	47·8	47·8
43·7	44·3	44·3	44·3	44·3	47·2	47·2	47·2	47·2	46·5	45·7	45·7	45·7	46·5
49·5	47·9	49·5	49·5	49·5	49·5	49·5	49·5	49·5	49·5	49·5	49·5	49·5	50·3
49·8	49·8	49·8	49·8	49·8	49·8	52·3	52·3	52·3	52·3	52·3	52·3	52·3	52·3
51·7	51·7	51·7	51·7	51·7	51·7	51·7	51·7	51·7	51·7	51·7	52·7	52·7	52·7
...	...	43·7	43·7	44·3	43·8	43·8	43·8	43·8	43·8	43·8	44·3	44·8	44·8
49·3	49·8	...	52·2	52·2	52·2	52·2	52·2	52·2	52·2	52·2	52·2	52·2	52·2
44·8	44·8	44·8	45·0	47·3	47·3	47·3	48·3	47·8	48·3	48·3	48·3	48·3	48·3
45·7	45·7	45·7	45·7	48·3	48·3	48·3	49·2	49·2	48·3	47·4	47·4	49·2	49·2
46·9	48·9	48·9	48·9	52·2	52·2	52·2	52·2	52·2	52·2	51·7	51·7	51·7	52·2
...	...	...	...	51·3	52·3	48·3	...	...	52·0	52·0	52·0	52·0	52·0
45·8	45·8	45·9	46·2	46·7	47·2	47·6	48·1	47·8	48·0	48·2	48·3	48·5	48·6

TABLE 6 (*continued to page* 191).

Particulars of selected Midland Locomotives 1832–97.

	Railway.	Engine.			Designer.
		No.	Name.	Date.	
a	Liverpool and Manchester .	...	Rocket	1829	Stephenson
b	Leicester and Swannington .	...	Comet	1832	Stephenson
c	do.	...	Samson	1833	Stephenson
d	do.	...	Liverpool	1834	Edward Bury
e	do.	...	Vulcan	1835	Tayleur and Co.
f	Birmingham and Gloucester, Lickey Incline .	...	Philadelphia	1840	Norris and Co., Philadelphia.
g	Midland . .	...	Jenny Lind	1847	E. B. Wilson and Co.
h	do.	...	Jenny Sharp	1847	Sharp Brothers
i	do.	120	...	1853	Sharp, Stewart and Co.
j	do.	80	...	1862	Matthew Kirtley
k	do.	800	...	1870	Matthew Kirtley
l	do.	1315	...	1876	S. W. Johnson
m	do.	1562	...	1882	do.
n	do.	1757	Beatrice	1886	do.
o	do.	25	...	1887	do.
p	do.	1853	...	1889	do.
q	do.	179	...	1893	do.
r	do. first type	116	*See Plate* 39	1896	do.
s	do. second ,,	150	*See Plate* 39	1897	do.
t	do. third ,,	2094	*See Plate* 41	1892	do.
u	do. fourth ,,	2236	*See Plate* 40	1895	do.
v	do. fifth ,,	1126	*See Plate* 40	1895	do.
w	do. sixth ,,	2360	*See Plate* 40	1897	do.

(*continued on next page*)

TABLE 6.

Particulars of selected Midland Locomotives 1832–97.

See Plates 30–31 *and* 39–41. Description of Engine.	Cylinders.		Diameter of Wheels.			
	Diameter.	Stroke.	Leading or Bogie.	Driving.	Trailing.	
	Ins.	Ins.	Ft. ins.	Ft. ins.	Ft. ins.	
Single driving wheels . .	8	16½	—	4 8½	2 6	*a*
Four wheels coupled . .	12	16	5 0	5 0	—	*b*
" " " . .	14	18	4 6	4 6	3 6	*c*
" " " . .	12	20	4 6	4 6	—	*d*
Six wheels coupled . .	16	20	4 6	4 6	4 6	*e*
Single driving wheels, and four-wheel bogie .	12½	20	2 6 2 6	4 0	—	*f*
Single driving wheels . .	15	20	4 0	6 0	4 0	*g*
" " " . .	16	20	3 6	5 6	3 6	*h*
" " " . .	16	22	4 0	6 6	4 0	*i*
Four wheels coupled . .	16½	24	4 0	6 0	6 0	*j*
" " " . .	17	24	4 0	6 6	6 6	*k*
Four wheels coupled, bogie .	17½	26	3 0 3 0	6 6	6 6	*l*
" " " .	18	26	3 6 3 6	6 9	6 9	*m*
Four wheels coupled, bogie; gold medal, Saltaire exhibition	18	26	3 6 3 6	7 0	7 0	*n*
Single driving wheels, bogie .	18	26	3 6 3 6	7 4	4 2½	*o*
Single driving wheels, bogie; grand prix, Paris .	18½	26	3 6 3 6	7 6	4 4	*p*
Single driving wheels, bogie .	19	26	3 6 3 6	7 6	4 4	*q*
" " " " .	19½	26	3 9½ 3 9½	7 9	4 4	*r*
Four wheels coupled, bogie .	19	26	3 6 3 6	7 0	7 0	*s*
Six wheels coupled . .	18	26	5 2½	5 2½	5 2½	*t*
Four wheels coupled, tank, trailing bogie . . .	18	24	5 3½	5 3½	3 0½ 3 0½	
Six wheels coupled, tank .	17	24	4 6½	4 6½	4 6½	*v*
Four wheels coupled, tank .	13	20	3 9½	3 9½	—	*w*

TABLE 6 (*continued from preceding page*).

Particulars of selected Midland Locomotives 1832–97.

	See Plates 30–31 *and* 39–41. Description of Engine. * approximate.	Steam Pressure per sq. inch.		Adhesion Weight.	Tractive Power.	Percentage of adhesion weight.
		Boiler.	Cylinder mean, taken at 75% of boiler.			
		Lbs.	Lbs.	Tons.	Lbs.	P. c.
a	Single driving wheels . .	50	37	*3·05	700	10
b	Four wheels coupled . .	60	45	9·47	1,728	8
c	,, ,, ,, . .	80	60	10·00	3,920	17
d	,, ,, ,, . .	? 80	60	10·00	3,200	14
e	Six wheels coupled . .	? 80	60	17·00	5,688	15
f	Single driving wheels, and four-wheel bogie .	63	48	10·00	...	...
g	Single driving wheels . .	120	90	10·00	5,625	25
h	,, ,, ,, . .	80	60	...	4,654	...
i	,, ,, ,, . .	120	90	12·70	...	...
j	Four wheels coupled . .	140	105	21·80	9,528	19
k	,, ,, ,, . .	140	105	24·05	9,337	17
l	Four wheels coupled, bogie .	140	105	26·80	10,718	18
m	,, ,, ,, ,, .	140	105	27·35	10,920	18
n	Four wheels coupled, bogie; gold medal, Saltaire exhibition	160	120	28·10	12,034	19
o	Single driving wheels, bogie .	160	120	17·50	11,487	29
p	Single driving wheels, bogie; grand prix, Paris	160	120	18·00	11,865	29
q	Single driving wheels, bogie .	160	120	18·00	12,515	31
r	,, ,, ,, ,, .	170	127	18·00	13,554	33
s	Four wheels coupled, bogie .	160	120	29·92	13,409	20
t	Six wheels coupled . .	150	112	39·46	15,163	17
u	Four wheels coupled, tank, trailing bogie . . .	150	112	30·57	13,776	20
v	Six wheels coupled, tank .	140	105	43·82	13,363	13
w	Four wheels coupled, tank .	140	105	22·98	7,800	15

(concluded from page 188) TABLE 6.

Particulars of selected Midland Locomotives 1832–97.

Heating Surface.			Grate Area.	Weight of Engine.		Weight of Tender.		Capacity of Tender.		Weight of Engine and Tender in working order.	
Tubes.	Fire-box.	Total.		Empty.	In working order.	Empty.	Loaded.	Fuel.	Water.		
Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.	Tons.	Tons.	Tons.	Tons.	Tons.	Gals.	Tons.	
117·7	20	137·7	6·0	...	4·25	...	3·20	...	...	7·45	*a*
* internal. ...	...	340	6·8	...	9·47	** approximate.	3·50	...	...	12·97	*b*
...	...	466	7·4	...	14·00		...	...	...	...	*c*
...	...	440	6·9	...	10·00		4·50	...	...	14·50	*d*
...	...	651	10·3	...	17·00		...	...	...	...	*e*
* 404	...	...	10·0	...	...		...	...	400	...	*f*
720	80	800	12·3	...	24·05	** 9·60	** 15·65	2½	800	39·70	*g*
847	72	919	...	...	21·45	** 8·00	** 13·05	1½	800	34·50	*h*
947	84	1031	14·5	26·75	29·25	11·80	20·05	2	1400	49·30	*i*
1025	88	1113	15·0	30·50	33·55	12·25	21·40	2	1600	54·95	*j*
989	99	1088	17·0	33·55	36·00	14·75	26·20	2½	2000	62·20	*k*
1113	110	1223	17·5	37·00	40·30	17·10	32·55	2½	2900	72·85	*l*
1032	110	1142	17·5	38·55	41·65	18·50	34·15	2½	2950	75·80	*m*
1150	110	1260	17·5	39·55	42·70	18·95	36·45	3	3250	79·15	*n*
1123	117	1240	19·5	40·35	43·20	18·95	36·45	3	3250	79·65	*o*
1123	117	1240	19·5	41·05	44·15	18·95	36·45	3	3250	80·60	*p*
1106	117	1223	19·5	41·05	44·20	18·95	36·45	3	3250	80·65	*q*
1105	128	1233	21·3	43·74	47·11	19·75	38·38	3	3500	85·49	*r*
1088	117	1205	19·5	41·16	44·17	18·97	36·49	...	3250	80·66	*s*
1150	110	1260	17·5	36·05	39·46	18·97	36·49	...	3250	75·95	*t*
1142	110	1252	16·0	41·43	51·02	...	...	...	1270	51·02	*u*
1024	96	1120	14·5	35·23	43·82	...	...	...	800	43·82	*v*
478	44	522	8·0	19·16	22·98	...	...	...	400	22·98	*w*

TABLE 7 (*continued to page* 195).

Particulars of selected modern Express Locomotives.

	Railway.	*See Plates* 41 to 48.	Engine.			Designer.
			No.	Name.	Date.	
		Plate.				
a	London and North Western	42	1502	Black Prince	1897	Francis W. Webb
b	Great Western .	43	3046	Lord of the Isles	1895	William Dean
c	North Eastern .	43	1870	...	1896	Wilson Worsdell
d	North British .	44	404	...	1894	Matthew Holmes
e	Great Eastern .	44	1030	...	1897	James Holden
f	Caledonian .	41	767	...	1897–8	John F. McIntosh
g	Great Northern .	42	990	...	1898	Henry A. Ivatt
h	London and South Western	45	720	...	1897	Dugald Drummond
i	Lancashire and Yorkshire	45	1093	...	1891	John A. F. Aspinall
j	Great Central .	46	268	...	1897	Harry Pollitt
k	London, Brighton, and South Coast	47	213	Bessemer	1897	Robert J. Billinton
l	South Eastern .	48	240	...	1889	James Stirling
m	Glasgow and South Western	48	11	...	1897	James Manson
n	Great Southern and Western of Ireland	46	62	...	1891	Henry A. Ivatt

(*continued on next page*) TABLE 7.

Particulars of selected modern Express Locomotives.

See Plates 41 to 48. Description of Engine.		Cylinders.		Diameter of Wheels.			
		Diameter.	Stroke.	Leading or Bogie.	Driving.	Trailing.	
		Ins.	Ins.	Ft. ins.	Ft. ins.	Ft. ins.	
Four wheels coupled, double radial truck; compound, four cylinders	2 cyls. 2 cyls.	15 19½	24 24	3 9 3 9	7 1	7 1	*a*
Single driving wheels, bogie		19	24	4 0 4 0	7 8	4 6	*b*
Four wheels coupled, bogie		20	26	3 7¼ 3 7¼	7 7¼	7 7¼	*c*
,, ,, ,, ,,		18	26	3 6 3 6	6 6	6 6	*d*
Four wheels coupled		18	24	4 0	7 0	7 0	*e*
Four wheels coupled, bogie; Dunalastair type		19	26	3 6 3 6	6 6	6 6	*f*
Four wheels coupled, bogie; ten wheels total		19	24	3 7½ 3 7½	6 7½ 6 7½	3 7½	*g*
Single driving wheels, bogie; four cylinders		15	26	3 7 3 7	6 7	6 7	*h*
Four wheels coupled, bogie		18	26	3 0½ 3 0½	7 3	7 3	*i*
,, ,, ,, ,,		18½	26	3 6 3 6	7 0	7 0	*j*
,, ,, ,, ,,		18	26	3 6 3 6	6 9	6 9	*k*
,, ,, ,, ,,		19	26	3 9 3 9	7 0	7 0	*l*
Four wheels coupled, bogie; four cyls.	2 outside cyls. 2 inside cyls.	12½ 14½	24 26	3 7½ 3 7½	6 9½	6 9½	*m*
Four wheels coupled, bogie		18	24	3 0 3 0	6 6	6 6	*n*

TABLE 7 (*continued from preceding page*).

Particulars of selected modern Express Locomotives.

	See Plates 41 to 48. Description of Engine.	Steam Pressure per sq. inch.		Adhesion Weight.	Tractive Power.	Percentage of adhesion weight.
		Boiler.	Cylinder mean, taken at 75% of boiler.			
		Lbs.	Lbs.	Tons.	Lbs.	P. c.
a	Four wheels coupled, double radial truck; compound, four cylinders	175	High 89 Low 76	34·10	13,813	18·0
b	Single driving wheels, bogie .	160	120	18·00	11,300	28·0
c	Four wheels coupled, bogie .	175	131	34·40	14,959	19·4
d	,, ,, ,, ,,	150	112	30·95	12,150	17·5
e	Four wheels coupled . .	160	120	27·59	11,108	17·9
f	Four wheels coupled, bogie; Dunalastair type	175	131	32·70	15,793	21·5
g	Four wheels coupled, bogie; ten wheels total	175	131	31·15	14,303	20·4
h	Single driving wheels, bogie; four cylinders	175	131	37·70	19,438	23·0
i	Four wheels coupled, bogie .	160	120	31·00	11,619	16·7
j	,, ,, ,, ,,	170	127	31·65	13,506	19·0
k	,, ,, ,, ,,	170	127	30·50	13,260	19·4
l	,, ,, ,, ,,	160	120	28·90	13,408	20·7
m	Four wheels coupled, bogie; four cylinders	165	124	31·75	13,994	19·6
n	Four wheels coupled, bogie .	150	112	24·60	11,215	20·3

(*concluded from page* 192) **TABLE 7.**

Particulars of selected modern Express Locomotives.

Heating Surface.			Grate Area.	Weight of Engine.		Weight of Tender.		Capacity of Tender.		Weight of Engine and Tender in working order.	
Tubes.	Fire-box.	Total.		Empty.	In working order.	Empty.	Loaded.	Coal.	Water.		
Sq. Ft.	Sq. Ft.	Sq. Ft.	Sq. Ft.	Tons.	Tons.	Tons.	Tons.	Tons.	Gals.	Tons.	
1241	159	1400	20·5	50·65	53·90	13·20	26·60	5	2000	80·50	*a*
1434	127	1561	20·8	45·30	49·00	18·11	35·50	4	3000	84·50	*b*
1089	127	1216	20·7	47·36	50·80	19·67	39·50	5	3940	90·30	*c*
1144	118	1262	20·0	42·77	46·00	15·85	32·00	5	2500	78·00	*d*
1116	101	1217	18·0	38·94	42·01	17·50	32·79	3½	2640	74·80	*e*
1381	119	1500	20·6	44·32	49·00	22·50	45·00	4½	4125	94·00	*f*
1302	140	1442	26·8	54·00	58·00	19·00	41·00	5	3670	99·00	*g*
1307	394	1701	27·4	50·20	54·55	22·20	40·00	5	4500	94·55	*h*
1109	108	1217	18·7	41·42	44·80	14·92	26·12	3	1800	70·92	*i*
1209	109	1318	20·0	44·25	46·80	21·05	41·50	5	4080	88·30	*j*
1350	110	1460	20·6	41·20	44·70	18·30	33·00	3½	2600	77·70	*k*
917	103	1020	16·7	38·55	42·50	16·00	30·50	4	2650	73·00	*l*
1094	111	1205	18·0	45·90	48·50	16·10	30·75	4	2500	79·25	*m*
938	112	1050	18·8	35·95	38·60	12·95	28·30	3½	2730	66·90	*n*

TABLE 8.

Midland Railway Locomotive Boilers broken up during ten years ending December 1896.

Class of Engine.	Number of Boilers broken up.	Life in years.		Mileage.	
		Mean.	Max.	Mean.	Max.
Passenger Tender . .	300	13¾	19¾	400,940	615,798
„ Tank .	60	18¼	23¼	360,917	442,198
Goods Tender . .	570	15¼	21½	369.497	655,829
„ Tank . .	70	17¾	25	433,417	574,561
All classes . .	1000	15	25	382,890	655,829

TABLE 9.

Midland Railway Locomotive Cylinders taken out during five years ending December 1896.

Class of Engine.	Number of Cylinders taken out.	Life in years.		Mileage.	
		Mean.	Max.	Mean.	Max.
Passenger Tender .	221	10	20	301,243	691,975
„ Tank .	61	12¾	27¼	280,444	455,304
Goods Tender . .	180	14½	27¼	349,808	685,018
„ Tank . .	46	14¾	25½	342,626	597,140
All classes . .	508	12¼	27¼	319,701	691,975

TABLE 10.

Midland Railway Locomotive Crank Axles taken out during five years ending December 1896.

Class of Engine.	Number of Crank Axles taken out.	Life in years.		Mileage.	
		Mean.	Max.	Mean.	Max.
Passenger Tender .	227	5	21¼	140,231	396,989
„ Tank .	34	8½	13¾	198,015	313,175
Goods Tender . .	742	7¾	24¾	189,501	614,857
„ Tank . .	106	13	24¼	313,318	634,602
All classes . .	1109	7¾	24¾	191,512	634,602

TABLE 11.

Midland Railway Locomotive Tires taken off during five years ending December 1896.

Class of Engine.	Number of Tires taken off.	Life in years.		Mileage.	
		Mean.	Max.	Mean.	Max.
Passenger Tender .	164	9¾	14¾	276,741	417,072
„ Tank .	129	5½	11¼	119,440	274,836
Goods Tender . .	854	6	11¾	144,882	290,031
„ Tank . .	243	4½	9	122,315	237,371
All classes . .	1390	6¼	14¾	154,133	417,072

TABLE 12.

Midland Railway Express Dining Trains now running between Bradford, Leeds, Birmingham, and Bristol.

Weights of Engine, Tender, and Vehicles.

See Plate 36.

Engine and Tender.

Engine, single driving wheels, bogie	47·112 tons.
Tender	38·375 „

Vehicles.

Composite bogie carriage, fitted with lavatory	31·250 „
Composite first class dining bogie carriage	31·650 „
Kitchen	14·850 „
Third class dining bogie carriage	30·600 „
Third class bogie carriage, fitted with lavatory	31·200 „
Guard's brake	12·500 „
Passengers and luggage	18·250 „
Total	255·787 tons.

TABLE 13 *(continued on opposite page).*

Midland Railway Passenger Carriages 1839–97.

Date.	*See Plates* 32–33. Description of Carriage.	Wheel Diameter.		Wheel Base.
		Ft.	ins.	Feet.
1839	First class, 3 compartments	3	0	8½
,,	Second class, 3 compartments, open from end to end above seat backs	3	0	...
1842	Third class, uncovered, seats round sides and ends, and in centre	3	0	8½
1844	Second class, 3 compartments, open from end to end, no glass in sides	3	0	8
1848	Composite tramcar, 1 second and 1 third class compartment	2	6	4½
,,	First class, 3 compartments	3	6	10
,,	First class, 2 compartments and coupé end	3	6	...
,,	Second class, 3 compartments	3	6	10
,,	Third class, 6 compts., 6 wheels (broad gauge), open from end to end above seat backs	3	6	18
1858	Second class, 3 compartments	3	6	10
1861	Composite, 2 first and 2 second class compts.	3	6	15
1865	Third class, 4 compartments, open from end to end above seat backs	3	6	12
1867	First class, 3 compartments	3	6	12
,,	Second class, 4 compartments	3	6	13
1874	Composite, 2 first, 2 third, and 1 luggage compartment	3	6	19
	Second class abolished 1875.			
1875	Composite, 3 firsts, 4 thirds, 1 luggage, six-wheeled bogies, monitor roof	3	6	46½ c 36
1877	Composite, 3 firsts, 2 thirds, 1 luggage, four-wheeled bogies	3	7½	33 c 25
1889	Composite, 3 firsts, 3 thirds, 1 luggage, 2 first and 2 third lavatories, six-wheeled bogies (grand prix, Paris)	3	7½	48½ c 37
1896	First class Dining, 1 dining & 1 smoking saloon, with kitchen and pantry, and ladies' and gentlemen's lavatories, six-wheeled bogies, monitor roof	3	7½	52½ c 41
1897	Composite * Dining, 2 first dining saloons, 1 first smoking compt., 3 third compts., and 2 first and 2 third lavatories	3	7½	52½ c 40
,,	Third class* Dining, 1 dining & 1 smoking saloon, and ladies' and gentlemen's lavatories	3	7½	52½ c 40

c = distance between centres of bogies.

* The cooking &c. for these two dining carriages is done in a separate cooking

(*concluded from opposite page*) TABLE 13.

Midland Railway Passenger Carriages 1839–97.

Body.		Compartments.		Number of Passengers to carry.	Weight.	Date.
Length.	Width.	Length between partitions.	Height from floor to roof in centre.			
Ft. ins.	Ft. ins.	Ft. ins.	Ft. ins.		Tons.	
15 6	6 6	4 11	5 0¼	12	...	1839
13 0	6 5½	4 2	5 4¼	24	...	”
17 9	8 5	...	...	...	...	1842
15 8	...	...	...	...	...	1844
11 0	6 6	2nd class 4 3 3rd class 6 6	5 8	26	...	1848
18 0	7 3	centre 5 10 ends 5 11¼	5 9	18	...	”
15 6	4 9	...	...	10	...	”
17 6	7 3	centre 5 9 ends 5 8¾	5 9	24	...	”
27 3	...	...	...	...	...	”
17 2	7 4	5 6	6 2	24	...	1858
23 0	7 6	1st class 6 2 2nd class 4 11½	6 6	28	...	1861
20 0	7 8	...	6 6	40	...	1865
20 0	7 8	6 6	6 6	18	...	1867
22 0	7 8	5 4	6 6	32	...	”
29 0	8 0	1st class 6 9 3rd class 5 3 luggage 4 0	7 1	32	10·25	1874
54 0	8 0	1st class 7 3 3rd class 5 11 luggage 7 3	8 4½	58	22·50	1875
40 0	8 0	1st class 7 3 3rd class 6 0 luggage 5 2½	7 4	38	17·35	1877
56 0	8 0	1st class 7 3 3rd class 6 0 lavatories 3 6 luggage 7 11	7 4	48	26·00	1889
60 0	8 0	12 6 and 23 9	8 6	18	34·75	1896
60 0	8 6	1st class 7 9 3rd class 6 6	8 8	15 first 28 third	31·65	1897
60 0	8 6	25 0	8 8	48	30·60	”

van, 31 feet long on six wheels, placed between the two carriages and communicating with them by means of flexible covered gangways.

TABLE 14.

Midland Railway Wagons 1844–97.

See Plates 34 to 36.

Date.	B = Brake Van W = Wagon	Wheel Diameter.		Wheel Base.	Length.		Width.		Tare.	Load to carry.
		Ft.	ins.	Feet.	Ft.	ins.	Ft.	ins.	Tons.	Tons.
1844	Low-sided Goods W	3	0	7½	14	7	7	9	...	6
1848	Goods Wagon .	3	0	8½	14	0	7	6	...	6
1845	Brake Wagon .	3	0	8½	13	0	7	6	...	6
1850	Timber Wagon .	3	0	6	10	0	7	5	...	6
1851	Cattle Wagon .	3	0	8	13	0	7	8	...	6
1858	Low-sided Goods W	3	0	8½	14	0	7	4	...	6
1861	Covered Cattle W .	3	0	9½	16	6	6	8	...	6
,,	20 ton Boiler Truck	3	0	15	23	0	6	10	8·50	20
1864	40 ,, ,, ,,	3	0	18	26	6	7	1	13·00	40
1897	High-sided Wagon .	3	2	9	14	11	7	5	5·12	8
,,	Covered Goods W .	3	2	10	16	6	7	5	5·57	8
,,	Long Cattle Wagon	3	2	11	19	1	8	0	6·20	8
,,	10 ton Goods B .	3	7⅛	9	15	0	7	6	10·00	...
,,	20 ,, ,, . .	3	2	10	18	1	7	6	20·00	...
1890	12 ton Case Wagon	3	2	18	30	0	8	0	8·90	8
1889	Twin Boiler Truck	3	2	9	*l* 36	0	6	8	*t* 12·30	30
1884	15 ton Truck . .	3	2	20	24	0	8	6	7·79	15
1882	18 ton Boiler Truck	3	6	22	28	2	8	0	13·92	18
1881	40 foot Case Wagon	2	8½	20	40	0	8	2	6·25	5
1889	40 ton Armour-Plate Truck .	3	2	18 *c* 12	24	0	8	3	18·52	40
1884	50 ton Truck . .	3	2	32 *c* 26	37	7½	8	8	25·25	50
1897	30 ton Boiler Truck	3	2	45 *c* 40	51	0	8	3	25·00	30

c = distance between centres of bogies.
l = length over both trucks.
t = tare of both trucks.

Permanent Way: Rails and Chairs.

See Plates 37–38.

Malleable iron rails introduced about the year 1805, at Wallbottle Colliery, near Newcastle-on-Tyne, by Mr. C. Nixon; the rails were square bars, two feet in length. In October 1820 Mr. John Birkinshaw of the Bedlington Iron Works obtained a patent for an improvement in the form of malleable iron rails, which were formed by passing bars of iron, when red hot, between rollers. These rails were generally formed in lengths of twelve to fifteen feet, fastened by wrought-iron keys into cast-iron chairs, which were spiked down to timber sleepers, about three feet apart. (See "Practical Treatise on Rail-Roads," by Nicholas Wood, published 1831.)

1.—Leicester and Swannington Railway, opened 17 July 1832. Wrought-iron rails of fish-belly pattern, similar to Birkinshaw's; 15 feet long, 3½ inches deep at centre between bearings and 2½ inches deep at chairs, fastened by wrought-iron keys into cast-iron chairs, which were spiked down to oak cross sleepers of half-round section, 8½ feet long, bound at the ends with an iron hoop. Rail joints made in a chair; rail ends square, held in position over joint chair by two wrought-iron keys; in ordinary chairs only one wrought-iron key was used. Weight of rail 35 lbs. per yard; ordinary chair 14 lbs., joint chair 17 lbs. Example in Leicester Museum, and also in Engineer's offices, Derby.

2.—Midland Counties Railway, between Rugby and Derby, opened 30 May 1839. Wrought-iron rails of double-headed pattern, keyed into cast-iron chairs, which were spiked down to blocks of Derbyshire millstone grit 5 feet apart; and also cast-iron chairs spiked down to Kyanised larch cross sleepers 3 feet apart. Rail joint made in a special joint-chair weighing 28 lbs.; ordinary chair 23 lbs. Weight of rail 78 lbs. per yard. (See "The Midland Railway, its Rise and Progress," by F. S. Williams; and Law and Burnell's "Civil Engineering.")

3.—Birmingham and Derby Railway, opened 30 June 1839. Wrought-iron rails, keyed by means of a wrought-iron ball and cotter into cast-iron chairs, which were spiked down to oak cross sleepers of half-round section. Weight of rail 56 lbs. per yard; length 15 feet. The rail being laid in the chair, the ball was pushed in through the transverse hole till it touched the web of the rail, and the split wrought-iron key was then driven in through the longitudinal hole, pressing the ball tight against the rail. The joints were made by a half lap, the two rail ends being held in position by a ball and cotter on each side. Weight of ordinary chair 20 lbs.; joint chair about 23 lbs.

4.—North Midland Railway, between Derby and Leeds, opened 11 May 1840. Wrought-iron rails of double-headed pattern, 65 lbs. per yard, keyed into cast-iron chairs, which were spiked down to timber cross sleepers. Rail joint made at a chair. Weight of ordinary chair 20 lbs.; joint chair 24 lbs.

5.—Birmingham and Gloucester Railway, opened 24 June 1840. Wrought-iron rails of flat-bottomed pattern, 56 lbs. per yard, laid in chairs spiked down on longitudinal timbers of triangular section, apex downwards, cut out of 14-inch square baulks; also on cross sleepers of half-round section 2½ feet apart. Rail secured in chair by outside wood key. Ordinary chair same section as joint chair, but narrower base. Weight of ordinary chair 17 lbs.; joint chair 25 lbs.

6.—Nottingham and Lincoln line, opened 6 August 1846; also Syston and Peterborough line, opened 2 May 1848. Wrought-iron rails of Tame Valley pattern, 65 lbs. per yard, keyed outside into cast-iron chairs, which were spiked down to uncreosoted sleepers. Weight of ordinary chair 18 lbs.; joint chair, similar pattern but wider, 30 lbs.

7.—Mr. W. H. Barlow's saddle-back pattern, introduced 1849, used on portions of main line and branches. Wrought-iron rails, originally about 125 lbs. per yard, laid directly on ballast without chairs, and held together by angle-iron ties 3 × 3 × ½ inch placed 10 feet apart. These ties not preventing the rails from rocking and spreading, they were replaced by wrought-iron sleepers of similar section to the rail, 10 feet apart; and finally by triangular timber transverse sleepers, into which the rails were notched and held down by dogs. Weight of rail finally 92 lbs. per yard. (See Proceedings Inst. C.E., 1850, vol. ix, page 391; and 1857, vol. xvi, page 246.)

8.—Midland Railway round-top rail, introduced 1850, used on portions of main line and branches. Wrought-iron rails of double-headed pattern, 80 lbs. per yard and 20 feet long, secured by outside wood keys in cast-iron chairs of 28 lbs. weight, which were spiked down to uncreosoted sleepers. Rail joints covered by ordinary fish-plates.

9.—Leicester and Hitchin line, opened 1 June 1857. Wrought-iron rails of double-headed pattern, 80 lbs. per yard and 20 feet long, secured by inside keys into cast-iron chairs of 34 lbs. weight.

10.—Bedford and London line, opened 13 July 1868. Originally wrought-iron rails. Finally steel rails of double-headed pattern, 83 lbs. per yard and 20 feet long, in cast-iron chairs of 34 lbs. weight and exactly same pattern as on Leicester and Hitchin line; inside keys.

11.—Settle and Carlisle rail, introduced 1870. Single-headed steel rails, 81 lbs. per yard and 24 feet long; chairs of 40 lbs. weight; inside keys.

12.—Improved Settle and Carlisle rail, introduced 1875. Single-headed steel rails, 83 lbs. per yard and 24 feet long; chairs of 40 lbs. weight; inside keys.

13.—Midland Railway 85 lbs. steel rail, introduced 1879. Length 30 feet; chair 40 lbs.; inside keys.

14.—Midland Railway 85 lbs. steel rail, introduced 1884. Length 30 feet; chair 50 lbs.; outside keys.

15.—Midland Railway 100 lbs. steel rail, introduced 1896. Length 36 feet; chair 54 lbs.; outside keys.

Examples of all the above are preserved in the Engineer's offices at Derby. The Midland Railway was incorporated 10 May 1844.

Sir DOUGLAS GALTON, Vice-President, was sure the members present had listened with the greatest interest to the highly valuable and comprehensive address which had been delivered to them by the President. The short lecture on political economy, with which it had opened, was one that might usefully be given to the country by mechanical engineers generally. If this part of the address could only be read by the artisans of the country, and the words of the President could be taken by them into their minds, he believed they would be ready to give up the folly of thinking that progress could be made by enabling the worst workmen to stand, in the matter of earnings, level with the best workmen. He well remembered the time before railways, when people used to travel by stage-coaches. At that time he went to school from Birmingham to Rugby by coach, and he had to start at an inconveniently early hour of the morning in order to arrive at the proper time. The school at Rugby in those days consisted of about three hundred boys; and owing to the limited coaching accommodation it was found necessary, when the boys went home for their holidays, to divide them into three groups to start on three successive days. Those who lived the furthest distance away started on the first day; those who lived within the next range of miles started on the second day; and those who had to go no more than about forty or fifty miles from Rugby left on the third day. Such a reminiscence sufficed to show how complete a change in all the ideas and all the habits of life had been brought about since that time by railways. The Midland Railway he thought had been the pioneer of railway progress; and this he had no doubt had been largely due to the excellent work of the President. The Midland Railway had been the first to start the third-class traffic in the country. The first trains which were run at a cheap rate were the penny-a-mile parliamentary trains, which were exempted from passenger duty; the railway companies were obliged to run one each way daily to every station on their lines. With few exceptions, those were formerly the only third-class trains allowed on any railway. When excursion trains at low fares began to be run, the companies sought for a similar exemption from duty in respect of these. Being then at the Board of Trade, he remembered the numerous applications received from the railway companies for remission of duty for excursion trains, as was the case with the parliamentary trains. Then Mr. Allport, general manager of the Midland Railway, and probably his friend Mr. Johnson assisting him, determined to run third-class carriages by every train. It was the Midland Railway that began this plan, which was now the custom over almost the whole country. The third-class traffic paid as well as any other traffic, or probably better; and it was astonishing that it had been so long neglected by railway managers. Therefore it must be said that the Midland Railway had initiated the third-class traffic. It was also the Midland Railway, he thought, which many years ago had initiated the idea of running full train-loads of coal to London, instead of leaving the city dependent, as it had previously been, on coal brought by ships. These were things which he himself recollected, though there must be many of those present who did not. The Midland Railway had also been the first, he thought, to import from America the Pullman car, which had given rise to a great many improvements in the carriages for passenger traffic; and now all the railways were rivalling one another in their endeavours to improve passenger accommodation. Some other points in American railway practice he could not help thinking were worthy of consideration; but probably the conditions of English traffic prevented their adoption here. One point was the greater compactness of the American goods trains. An experiment had been made some three or four years ago by running two trains, carrying an equal weight of goods, over a distance of seventy miles: one train on the London and North Western Railway, and the other on the New York, Ontario and Western Railroad. The English train was 1,120 feet long; the American was only 750 feet. The tractive force exerted upon the engine draw-bar, which included both the train resistances and the road resistances, was 6 lbs. per ton for the English train, against 3½ lbs. for the American. The American railroad too

(Sir Douglas Galton.)

was worse in gradients and curves than the portion run over of the London and North Western Railway. This was a very curious fact; but no doubt the conditions described in the President's address as affecting the working of English goods trains—the necessity of breaking them up so often, and various other matters—rendered it difficult to adopt the American methods of diminishing the resistances on the English trains. From the point of view of mechanical engineers he thought it might be said that, great as had been the railway progress in this country during the last sixty years, the advances in the near future would be much greater still. The underground lines, if they were to be comfortable, must be worked by electricity. In England he could not help thinking that electrical working would come in, as it had come in largely in America, to assist in solving a great many of the problems of railway management and construction which were now awaiting solution. It was upon mechanical engineers that the result depended; and he was sure the stimulating address to which they had listened this evening would lead the members to think more and more of the advances they might make, and that they would join with him in a most hearty vote of thanks to the President for his most interesting address.

Professor ALEXANDER B. W. KENNEDY, Past-President, had great pleasure in seconding the vote of thanks to the President for his address. Obviously the President had been anxious that the electrical people, who had for some years been mixing up finance with engineering in a way which was so delightful, and finance with graphics in a way which was even more fascinating, should not have the whole of the field to themselves. He had therefore taken this opportunity of showing that the older engineers could do just as well, and in some respects even better; for at any rate they could show curves of fluctuations of trade going back forty or fifty years, which the electrical people knew little or nothing about. Although not himself a railway engineer, he ought perhaps rightly to have been one; for he remembered that as a small boy his chief delight at the end of the week had been to spend the whole of his Saturdays at Stepney Junction Station, muddling about with the signalmen and engine-drivers, till the good-natured station-master finally thought it was time to turn him out. He had even turned his thoughts to practical locomotive engineering in those days, because he remembered making various improvements and submitting them to the drivers as they stopped at the station, and being much praised by them as a good little boy. Since then, although his practical interest in locomotive engineering had diminished, his actual interest in it had not abated; and he was very glad to be one of those who had had the pleasure of listening to an address such as that which the President had just delivered. It not only gave information which it appeared to him had never been made public before, but gave it with the most admirable clearness and frankness; and it would prove for many years to come a perfect mine of information to many of those interested in the matters here dealt with. If he dared to ask the President a question, it would be, how many horse-power-hours there were in a train-mile. Some day perhaps engineers would succeed in determining this relation. Meanwhile he had great pleasure in seconding the vote of thanks.

The vote of thanks was passed with applause.

The President thanked Sir Douglas Galton and Professor Kennedy for the kind manner in which they had proposed the vote of thanks to him for his address, and the members for the warm way in which they had received the motion. It had been rather a long address, he was afraid; but he could not get into a smaller compass all he wanted to say. It embraced a great variety of important subjects, and was practically a record of his own experience, and of the facts that had cropped up from time to time in his own department principally; and he had desired simply to give the facts as he found them, and not to make them either better or worse. He was strongly inclined to think there was a considerable future for electricity in connection with railways. Here he quite agreed with Sir Douglas Galton, and he had no doubt that Professor Kennedy also was likely to agree with them both. Whatever might be its nature, he understood there was some arrangement in contemplation

(The President.)

for working the Metropolitan Railway by electricity. If by this means the present traffic on such a railway could be as successfully worked as it had been by steam locomotives, then he thought the problem of the electric working of railways would be solved. For an underground railway no doubt it was most desirable that it should be so worked on account of the ventilation. If the ordinary main-line railways of the country could also be worked by electricity, one advantage would be that there would be less smoke in the atmosphere generally. It was a highly desirable object to achieve, if it could be done as economically as working by steam.

FIRST REPORT TO THE GAS-ENGINE RESEARCH COMMITTEE.

DESCRIPTION OF APPARATUS AND METHODS, AND PRELIMINARY RESULTS.

By Professor FREDERIC W. BURSTALL.

Object of Experiments.—The object aimed at in making these experiments is to determine the effect produced on the economy of Gas Engines by altering one or more of the conditions which govern their working. In internal-combustion engines there are a much larger number of factors to consider than in steam engines. Although the most favourable conditions of working for any particular gas engine may be known, it is difficult to ascertain whence the economy is derived. The factors to be considered are—the amount of compression, the speed, the ratio of air to gas, and the amount of heat which is to be rejected through the walls of the cylinder. An increase of compression, for example, is often regarded as conducive to more economical results; but it is uncertain whether the attendant increase in economy is really due to the compression alone, for it is clearly impossible to state with certainty the cause of any such economy, unless the conditions of working are altered successively one at a time. Experiments of this kind have repeatedly been made with steam engines of all sorts and sizes. The valuable results obtained by the late Mr. Willans show what an amount of information can be derived by varying one at a time the conditions of working the same engine. All the published results of tests made on gas engines are based upon only one fixed set of conditions, which have been arrived at by the makers in a more or less empirical manner. This dearth of information is no doubt due to the fact that gas engines have not hitherto been made for experimental purposes, and that it is difficult to get any reliable results when an ordinary gas engine is tried under conditions but little removed from those of normal working. For this reason it was decided to employ in these experiments one engine of rather small size, which was specially constructed for experimental purposes. It was of course known that the absolute economy of such an engine would be inferior to that of a larger one; but there seems no reason to suppose that the comparative economies under different conditions are different in the two sizes. Moreover, had the engine been of larger dimensions, it would have been impossible to measure with precision certain of the quantities, such as the volume of air. The present report deals entirely with the relative economies of the engine under varying conditions; but the apparatus has been arranged with the object of determining also a number of interesting theoretical points with regard to the combustion of the mixture, and also the relations between the temperatures and the ratios of air to gas in the working charge. This last portion of the investigation however has not yet been attempted.

All the measuring instruments employed have been calibrated by comparing them with some standard, as to the accuracy of which there could be no doubt. In several instances such a procedure has given rise to a great amount of labour and no little expenditure of time; but experimental work of a high class is frequently compromised by being carried out with instruments about whose accuracy no information is furnished. The experiments themselves may be perfectly accurate, and often are so; but it would be much more satisfactory if it were stated what precautions have been taken for determining the errors of the instruments employed. When a comparison is made of a number of results, it is always difficult to discover how far differences between them are due to real differences in the working conditions, or to inevitable experimental error. In a purely physical experiment, where the conditions can be regulated exactly and kept steady for a considerable time, it is possible to obtain results which are accurate to one part in a thousand; and in a few special cases still more precise results can be obtained. In an engineering experiment it is hopeless to expect such accuracy, owing to the great difficulty of keeping the working conditions sufficiently steady from beginning to end of the experiment. With ordinary care, and the use of appliances such as are found in all works, probably all that can be expected is to get results correct to three or four per cent.; with special care it is possible to get them as accurate as half of one per cent., but it is not suggested that all the results of the present experiments have this high degree of accuracy. The accuracy of any experiment is limited by the most inaccurate of the instruments employed. It would be almost too much to expect that every one of the complicated measurements involved in engine testing can be carried out with so great a degree of precision. In the principal measurements probably the experimental error involved does not in any case exceed one per cent.

In all the tests, with one exception, the dead weight on the brake was kept constant, and the power developed was rather more than half the full power of the engine. It would naturally have been better to make the tests at the full power; this was attempted, but was found to be impracticable under the varying conditions of speed, compression, and richness of charge; so it was considered most advantageous to select a power which the engine could develop under all conditions with ease. When first the installation was completed in London, it was intended to make a complete series of tests of the engine under all loads at various speeds and at various compressions; owing however to the subsequent removal of the engine to Birmingham, it has not yet been found possible to carry out the whole of these experiments, but it is hoped that in a future report a complete set of trials under all possible conditions may be presented to the Institution. The general arrangement of the engine and measuring apparatus is shown in the plan, Fig. 1, Plate 49.

Engine.—The engine used is of two horse-power nominal, and is capable of developing a maximum of five indicated horse-power. It was built by Messrs. Fielding and Platt of Gloucester, to whom the Committee are greatly indebted for many suggestions, and also for their kindness in altering it so as to adapt it for experimental purposes. The engine is of the ordinary horizontal kind, having a cylinder of 6 inches diameter and 12 inches stroke, Fig. 2, Plate 50. The whole of the valves are placed at the bottom of the cylinder, and worked in the ordinary manner by means of cams on the lay shaft, Figs. 3 to 5, Plates 51 and 52. There is considerable advantage in having all the valves on one detachable plate, as there is thus a minimum of surface exposed to the hot gases, and also the valves can be easily removed when leaking; the latter consideration is important in an experimental engine, where even a leakage so slight as not to affect the working of the engine would cause error in the measurements. The governing is effected by means of an ordinary Watt governor acting on a small roller, which causes a charge of gas to be cut out when the speed is too high. The variation in the speed is produced by altering the weights on the governor, the engine being capable of running at any speed between 120 and 205 revolutions a minute. At the lower speed the single fly-wheel is not sufficiently heavy for enabling the engine to run steadily; and therefore the results of tests made at the lower speed are not so satisfactory as those made at a higher.

In order to effect the required changes in the amount of the compression, the connecting-rod is so made that its length can be varied at will by means of packing pieces at the crank-pin head. To obtain low compression, the junk ring at the back of the piston, Fig. 2, Plate 50, can also be removed. The compressions employed in the experiments varied between 35 and 90 lbs. per square inch. The variation in the amount of gas admitted per charge is effected by throttling the gas as it enters the cylinder.

Measurement of the Gas supply.—The most usual method of determining the amount of gas used is by means of a wet test meter, which is of course perfectly satisfactory so far as measurement is concerned. The disadvantage of a meter is that it does not control the fluctuations of pressure which so frequently occur in the mains. A calibrated gas-holder H, Plate 49, has therefore been adopted as a means of measurement. It has a diameter of 6 feet and a working stroke of about 3 feet 4 inches, with a consequent capacity of about 100 cubic feet, which is sufficient for the requirements of any single test. The advantage obtained by the use of a gas-holder is that the pressure is perfectly constant from start to finish, and a single sample of gas taken from the holder is identical in composition with the gas used throughout the test. As a means of measurement of volume the gas-holder is certainly accurate to one-tenth of one per cent. The inner moving bell is carried by a single wire running over two pulleys, which are carried on ball bearings in order to reduce the friction. To the outer end of the wire are attached the counterbalance weights, which give a pressure inside the holder equal to 1½ inch of water. In order to guide the bell during its ascent, four small rollers are attached to it so as to roll on two vertical guide-rods. The volume of gas used during any given time is determined by measuring the height through which the inner bell has fallen. Three scales S are fastened to the inner bell at points on its circumference 120 degrees apart, and are read by means of pointers and small microscopes attached to the outer fixed bell; the object of using three scales is to eliminate the error which would be caused if the bell did not ride in a perfectly vertical line. The capacity of the holder was determined by comparison with a standard cubic foot measure, which was kindly lent by Messrs. Alexander Wright and Co., of Westminster. The holder was several times filled through the standard cubic foot, and the value of one division on the scales was thereby determined. The pressure and temperature of the gas were measured as it passed out of the holder: the pressure by means of a U gauge, and the temperature by a thermometer whose bulb was placed in the supply pipe. Special care was taken to prevent any leakage of gas either in the holder or in the supply pipes; and the use of the gas-holder rendered it easy to determine if any leakage existed.

Measurement of the Air supply.– In order to determine the amount of air used per stroke, it was considered advisable to measure the air by means of a meter. The usual method is to deduce it by calculation; the direct measurement of the air is believed to have been carried out in only two instances, first by Messrs. Brooks and Stewart of Hoboken, and next by Dr. A. Slaby of Berlin.

The arrangement of the air supply is practically the same as that employed by Dr. Slaby; but as his researches are not well known in this country, it may not be out of place to describe the method. The meter M employed, Plate 49, is a 400-light standard wet meter made by Messrs. Alexander Wright and Co., of Westminster. The air is forced into the meter by means of a Sturtevant blower B, which is driven by a small motor A; the pressure of the air is kept constant by means of a governor G. After passing through the meter, the air is delivered into what may be termed a safety box X, the purpose of which is twofold: firstly to prevent inflammable gas from passing back into the meter, and secondly to provide a relief in cases of back ignition. The first object is attained by making the air pass through a non-return valve; and the second by employing for the top of the safety box a loose lid, held in position only by being embedded in tallow. That such an arrangement is necessary has been proved on several occasions when back ignitions occurred; and nothing more serious then happened than the shutting of the non-return valve and the blowing of the cover off the safety box. Before the air reaches the engine it passes into a large rubber bag R, which prevents fluctuations of the pressure in the meter during the suction stroke. Although the direct measurement of the air supply is usually considered a difficult and somewhat dangerous undertaking, no difficulty has ever been found with this portion of the apparatus. The pressure and temperature of the air are measured by means of a gauge and thermometer similar to those used in the gas pipe. The air meter was checked by blowing air through it into the gas-holder, and was found to be correct to half of one per cent.

Measurement of Heat rejected into water jacket of cylinder.—Instead of employing the ordinary circulating tank, the cooling water is run from a calibrated tank T, Plate 49, through the water jacket, and thence is discharged. The capacity of the tank is sufficient to hold water enough for a single test. The temperatures of the inlet and outlet water are measured by means of thermometers, whose bulbs are immersed in the inlet and outlet pipes. For fixing the thermometers in the pipes, so as to prevent leakage and also to ensure that the readings of the thermometers are a correct indication of the temperature of the water or gas in which their bulbs are placed, the usual method is to employ a steel cup with very thin walls, which is screwed into the pipe; the interior of the cup is filled with mercury, and the bulb of the thermometer is placed therein. Such an arrangement naturally causes the thermometer to read always too low; and having a large thermal capacity it does not respond to rapid changes in the temperature of the fluid which is passing through the pipe. The method employed with the whole of the thermometers in the present experiments is to immerse the naked bulb into the pipe, leakage being prevented by soldering the glass stem of the thermometer to a screwed brass plug by means of Thomas's fusible metal; this metal has the great advantage of enabling glass and brass to be fixed together with a pressure-tight joint. The temperature of the jacket is kept constant by regulating the amount of water discharged, by means of a cock on the outlet pipe.

Method of sampling Exhaust Gases. — In determining the composition of the exhaust or flue gases, error occurs, not in the analysis itself, but in the difficulty of obtaining a true sample of the gas. A sample of the exhaust gas, as usually drawn out of the exhaust pipe at some time during the test, contains, in addition to the gases discharged from the cylinder, a quantity of air which comes in from the cylinder when a misfire occurs. Although it is possible to allow for this air, there can be no doubt that it is preferable to obtain a sample which contains nothing else than the gases themselves as they are discharged from the cylinder. The principle of the method employed in these experiments is to take a single bubble of gas from just below the exhaust valve after each explosion stroke. The apparatus employed is shown in Figs. 17 to 19, Plate 55. For the purpose of obtaining certain experimental data that do not form part of the present report, an electrical relay is employed, Fig. 25, Plate 57, which moves in such a manner as to complete any number of electrical circuits whenever the engine takes a charge of gas, and to keep these circuits closed until the end of the exhaust stroke. The possession of this relay rendered it a simple matter to arrange for an accurate and continuous sampling of the exhaust gas by means of a valve worked electrically. A circuit containing an electro magnet M, Figs. 17 and 18, Plate 55, is broken in two places, first at the relay, and secondly at a contact fixed to the exhaust valve; the latter contact is closed very soon after the exhaust valve commences to move, thereby exciting the electro magnet, which attracts the armature A fastened to a vibrating spring V; the outer end of the spring can just strike the spindle P of a small needle-valve N, which is held on its seat by a spiral spring S, Fig. 19. The opening of the valve allows a single bubble of gas to be sucked into the gas-receiver R. In order to prevent the sample from being contaminated by the air in the clearance space, there is placed behind the needle-valve a very small hole H of about 1–50th inch diameter, which communicates with the outer air, so that before the needle-valve has moved off its seat the gas in the clearance space is blown through this hole by the outward rush of the exhaust gas. The breaking of the circuit is effected by the relay lifting, which also is done by the movement of the exhaust valve; the two contacts on the exhaust valve are so arranged that one is broken almost immediately after the other is made. The sample of gas can thus be taken continuously and automatically, and contains nothing but the exhaust gas itself as discharged from the cylinder. The only possibility of error is in leakage past the needle-valve N, which necessarily becomes eroded by the escape of the very hot gas past its face; it was always tested for leakage, and when found to be defective was re-ground. The amount of gas collected is about 500 cubic centimetres or 32 cubic inches. The gas-receiver contained only mercury, so that no absorption of the carbonic acid was possible. The analysis was carried out immediately after the end of each test.

Measurement of Indicated Horse-Power.—In order to obtain an accurate measure of the indicated horse-power of a gas engine, it is necessary to keep in mind the fact that the conditions under which the indicator works are widely different from those occurring in a steam engine. Not only is the maximum pressure greater, but the pressure comes upon the piston of the indicator with the impulsive action of a blow; and the high temperature of the charge heats the indicator and its spring to a temperature which is unknown, but is certainly higher than anything met with in indicating a steam engine. The errors which are likely to occur when indicating either gas or steam engines are due to the following causes:—first, variation in the piston friction, caused by the heating up of the indicator, and by the uncertainty of the fit between the piston and the guiding cylinder; second, change in the scale of the spring, caused by the heating of the spring; third, inertia of the moving parts, which causes a positive error at the commencement of the stroke and a negative error towards the end; fourth, back-lash in the moving parts, which causes an apparent difference in the scale of the spring when a rising pressure changes to a falling pressure; fifth, friction of the tracing point on the paper; sixth, expansion or contraction of the paper, due to change in the moisture of the air after the diagram has been taken and before it has been measured up; seventh, difficulty of measuring accurately a somewhat small diagram; eighth, inertia of the paper drum; ninth, stretching of the string connecting the paper drum with the engine cross-head. These errors are not all of equal importance, and some of them tend to counteract others; but the existence of such a large number of probable errors considerably reduces the reliance that can be placed on an indicator diagram. It is thought probable that in many cases the indicated horse-power of a gas engine may be subject to an error which may be as large as 5 per cent.

The indicators employed in gas-engine tests are the Richards, Crosby, Darke, Tabor, and Wayne. For tests made in works the Richards is sufficiently accurate; but the inertia of its moving parts is so great as to render the breakage of its parallel motion by no means an uncommon occurrence; its use by gas-engine makers is probably due to the fact that it is not liable to injury from being used by unskilled persons. The Crosby indicator has been more used in accurate gas-engine tests than any other form; but it also is liable to somewhat serious errors, especially when the pins in the link-motion become worn. Considerable difficulty is frequently experienced from the indicator piston sticking in the cylinder; and of course the errors caused by the stretching of the string and by the inertia of the drum are present in this indicator. The Tabor and the Darke have both been used on gas engines; but the friction of the guiding pin or roller, which is employed to give a straight-line motion to the pencil, seems sufficient to render them unsuitable indicators for scientific purposes.

After considerable experience in the use of these four indicators, the conclusion was arrived at that the most promising instrument for accurate measurements is the rotary Wayne indicator. Owing to the fact that this is the most radical departure from the indicator as introduced by Watt, it seems to have been hitherto regarded with some suspicion; but in careful hands it is apparently the most accurate indicator at the present time. The indicator which has been used in these experiments is shown in Figs. 8 to 16, Plates 53 and 54. The singular feature it presents is the employment of a rotating piston P in place of a reciprocating piston. This rotating piston does not touch the containing cylinder at the outer extremities of the piston, but is guided at the centre in circular bearings; thus the piston friction is due to the friction in these bearings only, and is therefore small, and not liable to change, because the bearings can be well lubricated, and are not liable to have the oil swept off their surface as it is with the piston of an ordinary indicator. The Wayne indicator employed in these experiments was made by Messrs. Elliott Brothers, and contains several features which have been suggested by the reporter. The spring S, Fig. 16, is of the double helical pattern, and gives its readings from the twist, and not as in the ordinary indicator from the compression. When therefore the spring is twisted, it is shortened in the direction of its length; and some means has to be devised for allowing the spring to slide in the direction of its length without back-lash. This object is attained by fixing two hardened circular steel pins II, Figs. 14 and 15, to the body of the indicator; and the inner end of the spring terminates in a hardened steel plate having two slots L, Fig. 16, cut in it, which slide along the steel pins. Here naturally everything depends on the excellence of the workmanship; and in the indicator actually employed there is no perceptible back-lash between the end of the spring and the guiding pins, although the spring can slide freely along the pins. The outer end of the spring is rigidly connected to the indicator piston-rod R, Fig. 10; and the method of connection is such that, however the spring is put on, it always takes up one definite position. Across the piston-rod, which is made hollow for lightness, there is cut a V shaped slot V; the outer end of the spring has attached to it a ball B, Fig. 16, which fits closely the interior of the piston-rod; and the spring is held in by a screw in the piston-rod, which presses the circular wire against the V shaped groove. The constraint thus formed is equivalent to four points on a cylinder which is geometrically perfect; thus the spring can take up only one position. For eliminating the errors due to changes of temperature in the spring while in use and while being calibrated, it was kept at a temperature of 212° F. by surrounding it with a steam-jacket J, Fig. 8, supplied with steam from a small boiler.

One of the great advantages of the rotary indicator lies in the simplicity of the multiplying mechanism, which consists only of a light metallic tube T clamped to the piston-rod at the opposite end of the cylinder to the spring. In the interior of the tube slides a smaller tube, which carries the tracing point and is pressed outwards by means of a weak spiral spring. The motion of the tracing point is therefore circular, and the paper must be fastened to a curved frame F, Figs. 12 and 13, which is connected with the engine piston by suitable reducing mechanism.

For reducing the pencil friction to a minimum, and for preventing any change in the dimensions of the diagram, paper of any kind has been discarded, and has been replaced by a thin sheet of mica thinly coated with smoke. The tracing point, which is made of a hard drawing pencil, moves almost without friction over the smooth surface of the mica, and cuts away the smoke wherever it touches the mica. For preventing the smoke from being rubbed off, the diagram is then protected with a varnish composed of colourless lacquer diluted with alcohol; this is poured upon the mica, and after the excess has been drained off is set by gentle heat. After having been varnished, the diagram is perfectly unalterable; and from the nature of the smoke, the line traced by the pencil has clearly defined sharp edges, which render it possible to measure on the diagram with a microscope in the manner described later on.

The slide D carrying the diagram is driven in such a manner as to eliminate the error due to its inertia; the driving gear is shown in Figs. 6 and 7, Plate 52. The reducing gear made by Messrs. Fielding and Platt is of a particularly convenient kind; it consists of an oscillating shaft O, from which the indicator slide is intended to be driven; on the shaft is a long sleeve E, the axis of which is perpendicular to the shaft; and through the sleeve slides a bar M, jointed at its lower extremity to another bar N which forms part of the engine piston. As the use of a spring in the drum or slide of an indicator seems liable always to cause error, the slide is driven in both directions by the engine itself, and thus no lost motion can possibly occur, nor can the inertia of the slide cause an error unless the string or wire driving the slide stretches. The driving is effected by means of a fine steel wire W. The oscillating shaft O carries a light wheel U about 8 inches diameter, which can be rigidly attached at will to the shaft itself; and to the circumference of the wheel are fastened the ends of two steel wires, one of which is attached direct to the indicator slide, while the other passes round the circumference of a pulley Y equal in diameter to the wheel, and is then attached to the other extremity of the slide. The pulley Y can be shifted slightly, so as to alter the tension on the wire, which is always kept tight; hence the stress on the wire, instead of changing from tension to compression when the motion of the slide is reversed, as it does with the usual form of indicator gear, is always tension.

To obtain the true scale of the spring, the indicator is placed on a steam drum, in which the steam can be maintained steadily at any required pressure; communicating with the steam drum there is a large Crosby test-gauge, which can be read easily to ½ lb. per square inch. Both before and after the experiments the test-gauge was repeatedly compared with the mercury column at King's College, and the gauge errors were found to remain constant, at least over the period during which the indicator spring was tested. Readings were taken on the indicator, both with rising and with falling pressures, between 150 and 30 lbs. per square inch. Just before the indicator diagram was taken, the indicator was tapped lightly, so as to allow the piston to assume its true position. The distance between the atmospheric line and the height corresponding with any known pressure was measured by placing the mica sheet on the top of an accurately divided glass scale; and with the aid of a microscope the readings were made to 1-1,000th of an inch. The nominal scale of the spring was 1-200th, and a comparison of all the readings taken showed that the true scale was 1-198th. The greatest discrepancy which occurred in any one of the readings taken was less than 1 lb. per square inch.

Measurement of Indicator Diagrams.—Although the diagrams taken during any one test varied but little, it was deemed advisable to construct a mean diagram to represent the whole of the set taken during the test. From the nature of the arrangements adopted for driving the slide of the indicator, it is apparent that all the diagrams will be of exactly the same length; and this circumstance renders it possible to measure up the large number of diagrams with ease and precision. On a sheet of glass are ruled two sets of lines, one set vertical and the other horizontal; the latter are ruled one hundred to the inch, while the vertical lines are twenty in number, and are so arranged that they divide the length of the indicator diagram into twenty equal parts. The diagram to be measured is placed under the glass scale so that the atmospheric line coincides with the zero line of the glass scale, and the ends of the diagram lie on the two outer vertical lines. With the aid of a powerful magnifier a reading is then taken of the points where the vertical lines cut the curved lines of the diagram. After a little experience, this proved to be a most speedy and accurate method of obtaining the mean diagram; and although a number of different observers worked out the results, the reading could at any time be repeated to 1-200th of an inch. After a mean of the readings has been taken, the results are plotted to a large scale on squared paper accurately divided; and from this plotting all the final measurements are taken.

Method of Ignition.—The method used in the engine by the makers for igniting the charge is by means of an iron tube heated by a gas flame. In so small an engine there is not usually a timing valve, and the correct time of firing is regulated by heating a longer or shorter length of the iron ignition-tube. Some form of timing valve however seems absolutely necessary in all sizes of gas engines; and for economical and smooth running the time of firing has to be determined with great precision.

In default of a timing valve, it was decided to attempt to ignite the charge by means of an electric spark, as it was hoped that electric ignition would prove more certain and precise than any form of hot-tube igniter. Although all the reporter's endeavours to obtain a precise and certain ignition by means of a secondary spark have thus far ended in failure, it may be of interest to describe briefly some of the attempts that have been made. The failure has not resulted from insufficient experimenting, as more than four months have been spent in endeavouring to solve the problem of electric firing. It is true that in several kinds of commercial gas and oil engines electric ignition has been employed with perfectly satisfactory results; but in the experimental engine the problem to be solved is not quite the same as if the engine had to be used under only one fixed set of conditions. For the purposes of the present research a mode of ignition is required that will fire the gas with absolute certainty at any required time, and under no circumstances will ignite the charge either before or after that instant in the stroke. The two methods of electric ignition that have been used are: firstly by means of the secondary spark of an induction coil; and secondly by means of a spark resulting from the breaking of a circuit which contains a considerable amount of iron. The first plan was originally employed by Lenoir more than thirty years ago; and no doubt the uncertainty of the ignition so effected was one of the main reasons of the comparative failure of his engine. In the second plan the piston itself usually carries one of the contacts, which makes circuit with a contact fixed in the interior of the cylinder. The obvious defect of such a system is that the contacts are inside the cylinder, where it is difficult to get at them should they require alteration or repair. Moreover it would clearly have been impossible to employ internal contacts in the present experiments, as every change of compression would have required a re-arrangement of the internal contacts. From the experience gained however in the use of an induction coil, the chance of success is considered to be more probable when the second plan of ignition is employed. The Lenoir igniter consisted of two platinum wires, insulated from each other and projecting just inside the cylinder, together with some form of contact maker so arranged as to allow the spark from an induction coil to pass between the internal points. Starting with this arrangement, an endeavour was made to remedy the uncertainty in the firing by a more perfect insulation and by the use of a hotter spark. The induction coil adopted was capable of giving a spark of nearly 4 inches; the length of the spark was reduced and its diameter increased by putting a condenser in parallel with the secondary circuit. The insulation was improved by earthing one side of the coil, which rendered it possible to lead only one single wire into the interior of the engine. The contact maker was an ebonite disc, pierced with one small hole near its circumference, and rotating with the lay shaft; the circuit was broken by points placed on each side of the disc, so that when the space between the points was filled by the ebonite disc no spark could pass, but when the hole came between the points the spark could pass. In practice the defect of this form of igniter was its uncertainty: at low speeds it would ignite with great precision; but when the speed of the engine was raised, it occasionally happened that no spark would pass, although no fault could be found in the working of the coil. All attempts were unsuccessful in remedying this defect, which most probably is due to the fact that when the speed was raised the time for firing was so short as to render it uncertain whether at that instant there was the full potential difference across the spark gap.

The method of igniting finally adopted was by means of the ordinary iron tube, to which was added a timing valve, Figs. 20 to 22, Plate 56, worked electrically. The mechanical part of the valve is the same as that employed by Messrs. Crossley; the difference lies in the valve itself being worked by an electro-magnet M, Fig. 20, instead of by a cam on the lay shaft. On the circuit being broken by the contact breaker, Figs. 23 and 24, Plate 57, the armature A, Fig. 20, Plate 56, which normally holds the valve V on its seat, is released, thereby opening the valve V, Fig. 21, and thus putting the ignition tube in communication with the cylinder, and at the same time closing the escape valve E. There is a small hole H open to the atmosphere, which allows the products of combustion in the firing tube to pass out when the escape valve E is open, Fig. 22. The valve thus worked acts satisfactorily; the only difficulty occasionally experienced is too early an ignition, caused by the valve leaking. The hot tube however is regarded as only a temporary mode of ignition, because the life of iron tubes is so short, while with tubes of porcelain and numerous metallic alloys the ignition is not so prompt as with iron tubes.

Other apparatus.—The rope brake is of the ordinary kind, having the rope all round the brake pulley, with dead weights hung on the lower end of the rope and a spring-balance at the upper end. The revolutions were taken on a Harding counter fixed to the main shaft, and the explosions were recorded on another Harding counter driven from the gas-ignition valve. The samples of coal gas were drawn from the gas-holder into glass tubes, the ends of which were sealed up in the blow-pipe; the analyses of the coal gas were made by Mr. G. N. Huntly, B.Sc., who also supervised the analyses of the exhaust gas. The analyses of the coal gas are given in Table 1.

TABLE 1.—*Analyses of Coal Gas, percentage by volume.*

		Sample 1.	Sample 2.
Carbon Dioxide	CO_2	0·0	0·0
Heavy Hydrocarbons, taken as	C_3H_6	4·4	4·7
Oxygen	O	0·2	1·2
Carbon Monoxide	CO	4·8	7·0
Methane	CH_4	36·2	34·4
Hydrogen	H	46·7	45·8
Nitrogen, by difference	N	7·7	6·9
		100·0	100·0

The calculated volume of air required to burn one volume of gas into carbon dioxide and water is 5·61 in sample 1, and 5·47 in sample 2. The heating values per lb. of gas are 18,817 and 17,811 British thermal units respectively in the two samples.

Summary of Experiments.—The principal results of the seventeen experiments are shown in Table 2 (pages 226–7), and the indicator diagrams are plotted in Plates 58, 59, 60.

The ratio of air to gas is obtained by direct measurement, and is corrected for the quantity of air left in the clearance space. The usual method of finding this ratio is to assume that the cylinder and clearance space are filled with air and gas at an assumed temperature and at a pressure given by the diagram showing the suction stroke. In the case of these trials this method would give a result about 15 per cent. too large.

In finding the thermal efficiency, the mechanical equivalent of heat has been taken as 778 foot-lbs.

The mechanical efficiency of the engine varied from 76 to 84 per cent., the mean value for the whole seventeen tests being 81 per cent.

Trial 15 is a full-power test of the engine when running at 197 revolutions per minute; in all the other tests the dead load on the brake was constant.

Considering the three low-speed tests, Nos. 1–13–14, the most economical result is in test 13, in which the ratio of air to gas is 10·4. Although test 14 has double the compression of test 1, the two are nearly equal in economy. All three tests are distinctly uneconomical.

Taking the remaining results at speeds of about 160 and 204 revolutions per minute, the most striking feature shown is the importance of selecting a proper ratio of air to gas. It would seem probable that the influence of increased compression on economy is due to the fact that weaker charges can be burnt completely during the stroke when the compression is high. Considering tests 4–8–9–16, in which the ratio of air to gas is about 7·14, the thermal

TABLE 2 (*continued on opposite page*).—*Summary of Seventeen experiments.*

No. of Test.	Compression per sq. inch, absolute.	Clearance ÷ Cyl. vol.	Revolutions per minute.	Explosions, ratio of actual to max. possible.	Indicated Horse-Power.	Gas per I.H.P. per hour.	Heat Expended per I.H.P. per hour.	Heat Expended per explosion.	Thermal Efficiency.
No.	Lbs.	Ratio.	Revs.	Per cent.	I.H.P.	Cub. Feet.	Th. U.	Th. U.	Per cent.
1	52	0·57	118	89	1·72	33·0	20,122	13·61	12·6
2	62	0·49	161	50	2·65	25·6	15,698	17·2	16·2
3	64	0·49	158·3	58	2·69	25·9	16,517	16·2	15·5
4	64	0·49	164·3	52	2·79	27·3	16,557	18·15	15·4
5	65*	*0·46	204·4	67	3·79	26·9	16,300	14·95	15·6
6	65*	*0·46	204·2	88	3·41	32·1	18,975	11·96	13·4
7	72	0·41	156·2	64	2·87	23·3	14,111	13·46	18·0
8	74	0·41	158·2	53	2·44	29·7	17,964	17·3	14·4
9	76	0·36	157·7	55	2·61	27·7	16,706	16·8	15·24
10	80	0·36	155·5	69	2·61	24·05	14,460	11·76	17·65
11	83*	*0·37	154·2	69	2·50	26·55	15,548	12·2	16·4
12	83*	*0·37	154·9	61	2·52	35·1	21,663	19·3	11·7
13	86*	*0·37	117·6	75	1·84	28·2	17,041	11·9	15·0
14	102*	*0·25	117·7	78	1·60	31·1	18,734	10·85	13·6
15	103*	*0·25	197·2	92	5·10	20·35	12,186	10·95	21·0
16	105*	*0·25	157·5	70	2·48	30·28	19,018	14·27	13·4
17	105*	*0·25	148·9	85	2·56	23·8	14,171	9·58	18·0

* Junk ring added at back of piston.

TABLE 2 (*concluded from opposite page*).—*Summary of Seventeen Experiments.*

No. of Test.	Temperature of Jacket.		Heat given to jacket per explosion.	Vol. of Air ÷ Vol. of Gas.	Max. Pressure in cylinder per sq. inch, absolute.	Composition of Exhaust Gas, by volume.			
						By analysis.		By calculation.	
						Carbonic Acid, CO_2	Oxygen.	Carbonic Acid, CO_2	Oxygen.
No.	C°	= F°	Per cent.	Ratio.	Lbs.	Per cent.	Per cent.	Per cent.	Per cent.
1	61·0	141·8	28·6	9·1	118	6·0	10·0	6·3	8·1
2	62·7	144·9	35·0	8·0	211	7·6	6·4	7·2	6·4
3	64·7	148·5	31·8	8·36	171	7·2	7·4	7·1	7·76
4	63·5	146·3	41·5	7·13	203	8·0	5·2	8·2	5·0
5	64·5	148·1	37·1	8·35	167	7·2	7·6	7·0	8·0
6	60·8	141·4	28·5	8·48	105	7·2	7·6	7·0	7·96
7	62·7	144·9	37·2	9·48	171	6·0	9·6	6·0	8·6
8	66·0	150·8	45·2	7·18	237	8·2	5·6	8·1	4·7
9	65·0	149·0	42·8	7·08	230	8·2	5·8	8·2	5·6
10	71·3	160·3	40·6	10·1	161	5·2	10·8	5·1	9·0
11	56·5	133·7	41·8	8·75	203	6·5	7·0	6·6	7·8
12	75·6	168·1	30·9	5·28	286	9·3	0·4	*	*
13	60·0	140·0	41·5	10·4	179	6·2	9·4	5·6	10·5
14	60·8	141·4	42·6	9·25	210	5·4	10·6	6·4	9·1
15	62·0	143·6	35·4	8·6	201	6·8	8·6	6·9	8·1
16	59·0	138·2	32·8	7·18	278	7·4	6·6	8·3	5·4
17	67·0	152·6	29·0	10·8	135	3·6	11·6	5·4	10·9

* Could not be calculated, owing to insufficiency of air.

efficiencies are nearly the same, and the lowest, in test 16, occurs with the highest compression.

The most economical results, excepting test 15, are in Nos. 7 and 17, where the ratios of air to gas are 9·48 and 10·8 respectively.

Test 6 cannot be considered as comparing with the others, because the shape of the indicator diagrams shows that the gas was igniting too late in the stroke, Plate 58.

Test 12 is interesting as showing the result of employing a very rich charge.

Test 15 gives the thermal efficiency of 21 per cent., which is a very high figure when the small size of the engine is taken into account. Moreover it seems probable that more economical results than this could be obtained, as the ratio of air to gas was 8·6, which is certainly lower than necessary.

The tests seem to indicate that economy depends on the choice of the correct ratio of air to gas, and that this ratio increases with the compression. The number of experiments is not yet sufficient to determine what this ratio is for any given compression; but it is intended to make a sufficient number of experiments for determining this important point.

The Committee are indebted to Mr. E. C. G. Porter, Mr. W. H. Bell, and Mr. F. H. Hummel, for assistance in making the experiments; and to Mr. J. B. Wood for assistance in working out the results, and especially in making the drawings of the apparatus.

Previous Experiments, and Further Tests.—The experiments here published must not be regarded as conclusive. They were undertaken mainly to find out the directions in which future economy tests should be made, and were therefore carried out with a greater number of variations than would be desirable if they were intended to prove a general law. Previous experiments, in which the amount of air was measured, have been carried out on engines in which the volume of compression could not be varied. The best known of these experiments were made by Dr. Slaby on an Otto engine using the flame ignition. The amount of compression was small, and therefore the ratio of air to gas could be varied only between 5·5 and 7·5. The engine ran without the use of the governor, that is to say no explosions were missed. It therefore seemed that one of the objects of the present series of tests should be to extend the scope of the experiments in directions in which Dr. Slaby, owing to the construction of his engine, was unable to proceed. It was wished however to draw attention to the valuable nature of Dr. Slaby's investigations, with which the present experiments seemed to agree as regards those points that they have in common. The experiments which are now being carried out for the Committee, and which will form portion of a subsequent report, are at a constant speed. The quantities which are being varied are the load, the ratio of air to gas, and the compression. It would not be advisable to give at present the results of these tests, because in order to be of any service the complete set of experiments must be considered as a whole. It may be noted however that thus far they bear out the first experiments, in drawing attention to the advantages of using a suitable mixture, and in showing the importance of making an accurate analysis of the exhaust gases.

GAS-ENGINE RESEARCH COMMITTEE.

Professor Alexander B. W. Kennedy, LL.D., F.R.S., *Chairman.*
Mr. Henry R. J. Burstall.
Professor Frederic W. Burstall, *Reporter.*
Mr. Bryan Donkin.
Mr. John Fielding.
Mr. William H. Maw.
Mr. James Platt.
Professor W. C. Roberts-Austen, C.B., F.R.S.
Mr. Charles J. Wilson, F.I.C.

Discussion, 11 *February* 1898.

The President read a letter which he had received from Professor Kennedy, the Chairman of the Gas-Engine Research Committee, who greatly regretted that he had to travel northwards early this evening, and was therefore unable to attend the meeting as he had hoped to do.

Professor Alexander B. W. Kennedy, Past-President, wrote that, as a Member of the Institution who had been interested from the outset in the work of the Research Committees, and in particular as Chairman of the Gas-Engine Research Committee, whose first Report had just been prepared by Professor Burstall, he should like to say that he thought the investigations of this Committee were among the most important and the most interesting which had yet been undertaken by any Committee of the Institution. About eleven years ago, in connection with some gas-engine tests that he had had to carry out, he had endeavoured to make a heat account of a similar kind to those with which engineers were so familiar in connection with steam-engine trials, and which had proved of so much use. In other gas-engine trials, including the Society of Arts motor trials in 1888, he had also adopted this method. At that time there were no thermometric instruments suitable for making measurements of temperature in a gas engine with any approach to certainty or accuracy. The conditions of the case also, and, above all, questions of expense, rendered it impossible to make positive determinations on many points of the greatest importance; much had to be estimated or calculated. Notwithstanding all these drawbacks, the results, which had been published at the time, had proved he believed of considerable value. Although the actual figures had been only approximately correct, he had had the satisfaction of finding by experience that they were sufficiently near the truth to be of practical use in arriving at causes of defective working of gas engines in practice. Ever since that time he had been hoping that some one more fortunate than himself, and with better appliances, might be able to carry out similar tests with something like really scientific accuracy. He had therefore been particularly glad when the Council of the Institution had done him the honour of asking him to be Chairman of a Research Committee dealing with this subject, in connection with which the actual experiments would be carried out by Mr. (now Professor) F. W. Burstall, who he knew had already given particularly close attention to methods of measuring such temperatures as those occurring in a gas engine, and who was in every respect so well able to deal with the work.

The matter had been taken up by the Committee in the way laid down by the Council, which he thought had proved a highly sensible way: namely, in the first instance an endeavour had been made to find out what had been done before in the direction of the proposed investigation; and a careful statement had been drawn up of the nature of such previous work, so that it could be compared with the work proposed to be carried out. The ground having thus been cleared, the nature of the experiments to be made had been discussed by the Committee, and their general course decided upon. At this stage, as had so often happened before, various members of the Institution and others interested in the matter had shown themselves ready to help in a generous and effective manner. Their help having been fully acknowledged in the Report just read, he would only add a word to express the Committee's great indebtedness to their friend and colleague, the late Mr. James Platt of Gloucester, who not only through his firm had been the means of their obtaining a gas engine specially arranged for experimental purposes, but also by his advice and practical personal interest in the research had rendered great services to the Committee.

Even when however the engine, air-meter, gas-holder, &c., had been placed in Professor Burstall's hands to work with, there had yet remained a great mass of detail which had to fall upon him personally, and which he knew had occupied a large portion of his time during the last two years. Every one who had had to do with making accurate steam-engine tests knew that even these required a most careful

(Professor Alexander B. W. Kennedy.)

attention to many details. With a gas engine however, the complexity of the details to be attended to, and the difficulty of working them out, were altogether much greater than with a steam engine. Much of the apparatus employed had had to be absolutely designed from the beginning, and then tested, altered, and modified, until it actually met the practical requirements of the work. It would be remembered that the measurements were not, as they were with a steam engine, measurements which hitherto had often been made in some fashion or other; but that many of them were measurements which had never, or hardly ever, been made before at all. It had therefore not been a question of modifying and improving old apparatus to suit new conditions, so much as of devising new apparatus to suit conditions which as yet were themselves hardly known. The credit of doing this most difficult part of the work, of doing it successfully, and of doing it after most patient and laborious experiment, was to be given altogether to the reporter of the Committee, Professor Burstall; and he was glad to have this opportunity of saying from his own personal knowledge how valuable his work had been.

In these experiments the point which had been specially present to his own mind, as already intimated, had been that they should enable the results of gas-engine working to be put into the form of a heat account, such as that introduced on the Continent many years ago by Hirn for the steam engine, and independently adopted in this country at a somewhat later date by Sir Frederick Bramwell. The present Report dealt with the apparatus employed, and with what might be called the "preliminary" experiments, although the seventeen experiments here given did not include the large number of really preliminary experiments, of which the chief result had been to show that certain portions of the apparatus had not yet been got into a satisfactory condition. In connection with the experiments now described, a great many temperature measurements had been made. It had not yet been possible however to complete the working out of these; consequently the preliminary experiments here given were not presented as complete thermal experiments, the question of temperature not being dealt with at all. It was left for a second Report to describe the methods and apparatus finally used in the determination of the temperatures, and to deal with the thermal working out of gas-engine trials. From the results already obtained he had no doubt that Professor Burstall would be able in due course to show as complete a heat balance from a gas-engine test as those familiarly known in connection with the steam engine. This he believed would be one of the most important pieces of work that had been placed on record in what might be called "thermal engineering;" and he was extremely glad that it should have fallen to a Committee of the Institution of Mechanical Engineers to be the means of carrying it out.

Professor Burstall mentioned that, although the indicator traversing mechanism described in page 220 involved the error of rendering the travel of the indicator slide unequal in different portions of the stroke, this had been allowed for in the final plotting of the diagrams taken, and the diagrams shown were therefore not subject to the error. Since the experiments recorded in the Report had been made, a considerable number of other experiments on exactly the same lines had been carried out, which served to show clearly that the ratio of air to gas could be determined without using an air meter, by an accurate analysis of the exhaust gas. In boiler tests it was recognized as a simple matter to ascertain the air drawn through the furnace by an analysis of the exhaust gas; and in just the same way in a gas engine the amount of air which had been used could be found by analysing the exhaust gas. This was a safer and certainly a much more accurate method than the usual mode of estimating it by difference of volume in the cylinder of the gas engine. In the next Report he trusted to be able to produce evidence enough for proving this point conclusively. The engine had now two fly-wheels, whereas at the time of making the experiments here recorded it had only one. The reason why the thermal balances had not been given was not because they had not been worked out, but because it was considered that the thermal side of the subject formed a separate branch by itself. The present Report dealt merely with the economy of the engine under relative conditions.

Mr. Dugald Clerk was sure that all gas engineers who had been designing and constructing gas engines for years past would feel exceedingly indebted to the Institution for taking up this subject. In ordinary work it was naturally impracticable to use the refinements which had been described in the Report. Important results he was confident must follow such careful and accurate work as that here recorded; and no doubt in time a better understanding of the conditions of economy in gas engines would be arrived at. Thus far however the experiments appeared to him to have been conducted with perhaps insufficient experience of the most important matter to be dealt with, namely the engine itself. Great care and minuteness had been devoted to the errors of the indicator, the errors of the thermometers, the proportion of air to gas, the temperature of the entering air, the temperature of the exhaust water and engine water, and other details; and no doubt the results had been given with great accuracy, and from these experiments could be drawn up the heat balances about which Professor Kennedy had written. But more than a heat balance was required for understanding the conditions of economy in a gas engine. For example, it depended entirely on the particular engine used whether economy was increased or diminished by increased compression. A gas engine could be so constructed that the increase of compression, keeping every other condition the same, would produce an actual diminution of economy. For instance, in the old Otto slide-valve engine, first introduced into this country about 1877, in which a slide-valve was used for ignition, the slide-valve communicated with the combustion space by means of a port, and the port had a considerable capacity. Moreover the exhaust valve, which also communicated with the cylinder through a port, was situated apart from the cylinder in a valve-box by itself. The port was of large capacity, and the valve-box space was of larger capacity than that of the port leading to it. The proportion of port capacity to the whole clearance space, that is, to the capacity of the compression space, was large; in the old Otto engines it would amount to as much as 25 per cent. of the whole compression space. Having himself begun to work on gas engines in 1876, and an attempt having been made about 1879 by Messrs. Crossley to increase the compression, he had tried experiments with increased compression in their engines, and had invariably found that increase of compression in the old engines meant not an increase but a diminution in economy. The reason was simple. The large exhaust-port, leading to an exhaust-valve chamber of fair size, had a rapid cooling action. When the explosive mixture was ignited, the flame passed through the port, and the exploded gas was rapidly cooled in so passing; and an increase in compression with engines having large exhaust-port space invariably resulted in a great increase in cooling, because of the fact that diminishing the actual compression space increased the proportion of port space to compression space. In most gas engines constructed nowadays the compression was carried up to 90 lbs. per square inch above the atmosphere; but in the old days it was only 35 lbs. per square inch. If in one of those old engines the compression were raised to 90 lbs. per square inch, there would to begin with be a great difficulty in connection with the slide-valve, and there would also be a diminution of economy, instead of an increase. The engine shown in Plates 50 to 52 appeared to him not suited for carrying out experiments of the kind described in the Report; and he anticipated that the heat balance obtained from such an engine would be a specially bad heat balance at high compression. With the cylinder liner carried back into the compression space only so far as was shown in Plate 50, it appeared to him that, when the piston stroke was made to extend further inwards for increasing the compression, it would sometimes produce an annulus of piston surface projecting into the compression space; and he asked how far back the piston ever came in for producing high compression.

Professor **Burstall** replied that with high compression the innermost spring-ring on the piston only just failed to clear the liner.

Mr. **Clerk** feared that was a fatal objection, because the annulus presented by the piston projecting beyond the end of the liner

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constituted an increased cooling surface, which had a peculiarly bad effect in increasing the fuel consumption at high compression. It was difficult indeed to make a gas engine which would, under identical conditions of admission of mixture, produce the same mixture in the cylinder under different conditions of compression. If the compression was increased by simply pushing the piston further in, unless certain precautions had been observed beforehand in constructing the engine, an increase in economy would not be obtained corresponding with the increased compression; that is, the theoretical thermal advantage of increased compression would not be gained. Whether a slight economy or even sometimes an actual loss would result could not be predicted without actually measuring up the engine spaces. This was a point therefore which he thought as the experiments proceeded should be carefully considered, to see that the engine was adapted for carrying out the conditions of economy at high compression.

Another point in a small engine such as was used in these experiments, having a 6-inch cylinder with 12-inch stroke, was the loss by leakage. Even a small leakage would here have a great effect. When testing an engine of this class with a brake, he had often noticed that, if the indicator cock were opened for more than an instant in taking a diagram, there was immediately a considerable falling off in speed; the slight leakage through an ordinary Richards indicator was enough to affect a small engine of this kind. Instead of using alone the closed-tube igniter, which he believed had really been proved universally to be the best for small engines, he noticed that a timing valve was added to it (page 223). A timing valve of the kind shown in Plate 56 he considered was too severe upon a small engine by involving loss of mixture. If the ignition tube was at the far end of the port, beyond the timing valve, he feared there would be some difficulty, because a considerable blow-through would have to take place after each ignition. Apart from this however, when the engine was running at its slowest speed of about 118 revolutions per minute, which was a slower speed than was ever used in practice, an appreciable proportion of the whole contents of the cylinder would be discharged through the timing valve previous to ignition; and in this way also there would be a loss of economy. In the experiments themselves he admitted that economy was relatively of no importance; but in view of all other measurements having been here carried to such an extreme accuracy as one per cent. or half of one per cent., the economy he thought might advantageously receive equally minute consideration. As the result of this and various other points which he noticed about the engine, he imagined there might easily be occasioned a loss of economy not far short of 10 per cent. With the timing valve it was evident that, at the moment of its opening, an appreciable part of the contents of the cylinder had to be discharged through the pocket of the valve and then through a small discharge hole, in order to clear out the entire space of the port before the explosive mixture could reach the igniting tube. Consequently a larger proportion of explosive mixture would be lost at a higher compression than at a lower. In order therefore to ascertain whether the economy was improved or the reverse by using compression, it would be necessary to be most careful that the proportional losses were the same; in the present engine it seemed hardly possible that they could be the same.

Economy depended also largely upon the nature of the explosive mixture used. A paper he had read before the Institution of Civil Engineers in 1882 (vol. lxix, page 220) had recorded a set of experiments he had made on gaseous explosions, whereby he had found that the best mixture to produce the maximum initial pressure and the longest duration of pressure was ten volumes of air to one of gas. Gas engines were now generally designed and constructed for using a mixture not much stronger or weaker than either nine to one or eleven to one. It was well known that if anything like so strong a mixture was used as in tests 15 and 16 in Table 2, namely 8·6 to 1 or 7·18 to 1, a condition was at once set up, under which economy became impossible. The maximum temperature of the flame was too great, the average temperature throughout the stroke was too great, and the loss was much too great. Hence in the practical working of gas engines it had long been the custom to use a mixture of about eleven to one; and it was well understood that, if

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this proportion were largely departed from, the results were not so good.

The seventeen experiments summarised in Table 2 he feared had not proved much, because the conditions were too mixed. It was rightly laid down at the outset of the Report that uniformity in the conditions was necessary, and that only one change at a time should be made in them; but in these experiments he did not see much trace of this principle having been followed. The conditions were not here varied one at a time, nor did there seem to be a sufficient number of experiments under any of the conditions to make sure of the result.

There was another point which involved much difficulty, and which also largely determined economy in a gas engine. Supposing a timing valve to be adjusted for igniting, at a certain point in the stroke, a weak mixture, such as ten volumes of air to one of gas, thereby producing a certain economy: it would be found that, if the mixture were enriched to say eight volumes of air to one of gas, there would then be a considerable drop in economy; and an indicator diagram would be obtained somewhat similar to that shown in Fig. 12, Plate 59, where the ignition line appeared to go straight up in a vertical line. If however, without altering the proportions of the mixture in any way, the timing valve was altered so as to make the mixture ignite a little later than before, it would be found that, notwithstanding the richer mixture, an imprvoement in economy had been obtained. And even with the stronger mixture economy was obtained by igniting in such a way that the ignition line, instead of going straight up vertically, inclined a little forwards. The reason was simply that the time taken by the crank in crossing the centre at the end of the stroke bore a considerable ratio to that of the whole revolution; and if the engine was running at a high number of revolutions per minute, it was necessary that the igniting valve should be opened and the ignition started while the crank was still on the centre, in order that the maximum pressure might be reached within about one-tenth of the forward stroke, which must be done if any economy was to be realised. With the richer mixture the ignition started at once, and flame existed in the cylinder for perhaps a full tenth of the stroke; and the consequence was that the ignition line in the diagram, instead of being inclined forwards, was vertical and showed a loss. An extreme instance of the opposite condition was seen in Fig. 6, Plate 58, where the ignition had gone forwards through about 35 per cent. of the stroke. That was also an uneconomical condition, for the reason pointed out in page 228; besides which there were also other reasons for a loss. One was that the engine was now not really working at the compression which it seemed to have, but was really working in the same way as at a lower compression, because it was seen that only a small part of the diagram had any of the benefit of the initial compression. Another reason was that the combustion was also incomplete, and the contents of the cylinder were discharged at the end of the stroke only partially burned. Thus there were many difficulties in dealing with a gas engine, altogether apart from the difficulties of measurements.

Yet another point also that had to be watched carefully in the experiments was the effect of the change of speed. Theoretically, assuming that an engine was giving the same indicator diagram at a low speed and at a high speed, the high speed should be more economical: if the valve ports and areas were properly proportioned, the economy was greater at a high speed than at a low. But if the proportions were improper, a change of speed produced an entire change in the nature of the explosive mixture and in the point of maximum pressure in the cylinder: such a change indeed as might even cause running at a high speed to be attended with a loss as compared with the running of the same engine at a low speed.

The arrangements for research work of this kind therefore could not be too carefully considered: first in connection with the construction of the engine; and secondly in the selection of the igniter. For such experiments it was not proper in his opinion to use an igniter discharging part of the cylinder contents through a by-pass and a valve, as was here done; electric ignition, notwithstanding its difficulties, he considered would have been better; and better still would have been an open-tube igniter properly adjusted. There was no difficulty about adjusting it to get the diagrams required. Thirdly, a whole series of experiments should be made with the best mixture, with successive gradations of compression from the lowest to the highest. Otherwise it might be concluded that compression instead of being good was an evil, and that high speed instead of being an advantage was also an evil. These criticisms he trusted would not appear too censorious, in view of the importance of so many minute conditions which were not readily evident to any but those who were daily engaged in the working of gas engines, because it was so difficult to test such an engine, to get a true heat-balance, and to understand thoroughly the minute points which made all the difference between economy and want of economy.

Mr. JAMES ATKINSON recognised the careful way in which the heat expenditure in the gas engine had been estimated in these interesting experiments, although in regard to some of the arrangements he was afraid he must agree with Mr. Clerk's criticisms. Having been making tests of gas engines almost daily for the last eighteen years, he should never dream of taking an indicator test from a small gas engine; the errors were far too great for an accurate indicator diagram to be obtained from a small engine. The nature of the difficulty was exemplified by the tale, which had come down from the early days of steam navigation, about a small paddle-boat built with rather too small a boiler and rather too large a whistle on the boiler; so that unfortunately the owner found when he wanted to whistle he could not paddle, and when he wanted to paddle he could not whistle. The same was to some extent the case when an indicator was applied to a small gas engine. The losses were so serious that no satisfactory result could be deduced; and it was much better that the indicator should be used simply to define the compression pressure and the timing of the ignition, and that all the results should really be taken from the brake test. In the Wayne indicator it was mentioned in page 218 that the extremities of the rotating piston did not touch the cylinder: which could only mean that there must be considerable leakage past those extremities; and the amount of the leakage would vary much with the speed at which the engine was running. A little leakage past an indicator when applied to a steam engine was not so serious a matter, because it was the pressure during the working stroke that was being considered; but in a gas engine an indicator had to record the pressure of the mixture all the time during its compression, before it was ignited, and probably for some time after the ignition had actually taken place, because the mixture in the indicator passage was not ignited possibly for some little time afterwards. Consequently the leakage of unexploded mixture past an indicator on a gas engine was much more serious than it was past a steam-engine indicator.

In the arrangement of the rope brake (page 224) he enquired whether the spring-balance was made to take the gross load and the dead weights to constitute the negative load.

Professor Burstall replied that the brake pulley was driven the other way round, so that the dead weights constituted the gross load, and the spring-balance was in favour of the engine.

Mr. Atkinson had always found it difficult to read accurately a heavy load taken on a brake with a spring-balance. It was much more satisfactory to lift an actual dead load; and he was glad to hear that this was what had been done.

It was gratifying to learn that the Crossley timing valve had been found to act satisfactorily for igniting (page 224); but he could not quite agree with the remark about the ignition being not so prompt with tubes of porcelain and of different metallic alloys as with iron tubes. Inasmuch as 7,000 or 8,000 gas engines had been made by Messrs. Crossley with porcelain-tube igniters, and this had always been found a highly satisfactory arrangement, he had himself taken an indicator diagram from an engine using a porcelain igniter. The diagram was shown in Fig. 26, Plate 60, and had been drawn by fifty consecutive explosions. It showed that the ignitions were not only prompt, but in all respects as satisfactory he thought as could be desired. An enlargement made by photography was interesting as showing that the line of the diagram was not a clear continuous line, but consisted of what might be termed a series of minute jumps. The original diagram had been taken with a lead pencil, which he thought was much better for accuracy than a metallic marker; and the jumps showed that the friction of the lead pencil on the rough surface of the paper did not in any way cause any error in the diagram, because when the pencil jumped over one of the minute spaces in the surface of the paper it would alight again upon the paper in the proper position which it ought to occupy under the action of the indicator spring. For prompt ignition he believed porcelain tubes were really quite as satisfactory as iron tubes.

In pages 224–5 was given the analysis of the coal gas, and its heating value per lb.; but not the number of cubic feet per lb., which was also necessary to be known. Although this could be worked out from the analysis, it would be useful if it were added in the Report. The next Report he was glad to note would give some heat tables, which were always useful and interesting.

Mr. WILLIAM SCHÖNHEYDER asked what indicator had been used for the diagram shown by Mr. Atkinson.

Mr. ATKINSON replied that the indicator with which the diagram shown in Fig. 26, Plate 60, had been taken was a modified Richards indicator, specially constructed in one or two details. The Richards indicator as usually made had rather too weak a piston-rod. In the indicator he had used the piston-rod had been considerably enlarged; and the lever gear had also been strengthened, and made a little more satisfactory in other respects. The diagram had been taken with a strong spring of 180 lbs. to the inch; when a weaker spring was used, the indicator piston was driven up to the stop with such violence by the explosion that in the indicator as ordinarily constructed the stop was not sufficiently strong. In the special make of indicator which he had found really the best for withstanding the wear and tear, the top cover was a spring plate, with a substantial stop to come up against, so that the gear was not injured if it struck the stop rather hard.

Mr. DRUITT HALPIN noticed that the Wayne indicator shown in Plates 53 and 54 seemed almost identical with one made in Camden Town from Mr. Michael Longridge's design about twenty years ago. The only difference he could see was that, small as was the inertia of the twisting helical spring here shown, the inertia in Mr. Longridge's indicator was still smaller, because, instead of a helical spring round the spindle of the piston, there was simply a straight bar that was strained in torsion. It might be of interest if Mr. Longridge would supply a drawing of the instrument which he had had made for himself about 1879.

Professor WILLIAM ROBINSON thought Professor Burstall was to be congratulated on the extreme care he had taken in the calibration of the measuring instruments by comparison with standards; that precaution was too often neglected. For the last few years he had himself been using the Wayne indicator with great satisfaction. There was no mention in the Report of the pressures during the pumping strokes, which he presumed had been taken from light-spring diagrams. It would be interesting to see some of these light-spring diagrams, and to contrast them with the pressure diagrams; they were necessary for finding the effective indicated horse-power with the degree of accuracy aimed at. No mention had been made of the readings of the barometer, which he supposed had been used in working out the results of the experiments, because the variation in the barometer would affect the quantity of gas measured. Then again the state of the air, whether dry or moist, might have an appreciable effect, though not much. Attention seemed to have been given mainly to the indicated horse-power, and there was no record of the brake horse-power for each test. Nothing was said about the duration of each test, nor about the number of observations taken. Besides calculating the heating values for the coal gas, he asked whether these had been observed directly by means of a Junkers calorimeter working continuously; the figures so obtained would at any rate serve as a check upon the values calculated by the ordinary roundabout method from analyses.

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It seemed to him a mistake to attribute the apparent dearth of information to the fact that gas engines had not hitherto been made for experimental purposes (page 209); for he thought it was possible some makers of gas engines might know to their cost that they had made too many experimental engines, and perhaps not enough of the working kind for practical and commercial purposes. The fact that the results of such private experiments had not been published was much to be regretted, and that the record of failures had not been made known. It would have saved a great deal of subsequent work if such information had been available.

The laudable intention with which the Report started, of varying only one condition at a time, was rather difficult to carry out with an engine such as had been selected by the Committee, for the same reason as that given in page 210, namely that the conditions were but little removed from those of normal working. Perhaps if an engine had been built on the lines of the "Cycle" gas engine with which Mr. Atkinson had made experiments, it might have been managed a little better to vary only one condition at a time. It was pretty well known that, with a gas engine properly designed, the efficiency or economy would be increased by increase of speed up to a certain point. A series of experiments could easily be made at different speeds, and the results plotted would show the relation between speed and efficiency or gas consumption per brake or indicated horse-power per hour. It was also possible, and advantage was taken of the fact, to increase the compression and thereby to increase the efficiency; but as to the adaptability of the selected experimental engine for this purpose, he agreed with what Mr. Clerk had said on this score. In test 4, Table 2, for example, the ratio of the clearance to the cylinder volume was 49 to 100, or practically one half; whereas in test 16 it was only 25 to 100, or one quarter. It would perhaps at first appear as though the only condition here varied was the compression: the mixture used was nearly the same, the ratio of the volume of air to gas being respectively 7·13 and 7·18; and the speed was also nearly the same, namely 164·3 and 157·5 revolutions per minute. Yet the consumption came out with the low compression 27·3 cubic feet of gas per indicated horse-power per hour in test 4, and with the high compression 30·28 cubic feet in test 16. It was therefore not necessary to go back to old engines in order to see where waste of gas would occur; here there was a much higher compression giving a lower economy, which was contrary to everyday experience with well-designed gas-engines. From a closer examination and comparison of the results of tests 4 and 16, and of the indicator diagrams from these tests, it was abundantly evident that, owing to the unsatisfactory arrangement of the engine, the conditions had not been altered one at a time, as proposed; and consequently when the compression was increased, whilst the ratio of air to gas and the speed were kept nearly constant, it did not follow that the reduction in economy here recorded was due to increase of compression alone. For instance, in these two tests, besides change in compression, it followed from the method adopted, firstly, that the quantity of mixture dealt with in each charge was reduced from test 4 to test 16 in the ratio of six to five; and therefore more numerous explosions were required in test 16, when the engine was being forced to give out nearly the same power as in test 4. Thus the ratio of actual explosions to the maximum possible was increased from 52 per cent. in test 4 up to 70 per cent. in test 16: so that with fewer cut-outs the cylinder was not allowed to cool in test 16, nor were the products of combustion so well mixed with air and cleared away. Hence the actual mixture in the cylinder could not be the same in the two tests. On the other hand it would be seen, secondly, that the cooling surface of the cylinder walls exposed to the gases was reduced in test 16; and, other things being equal, this would cause less loss of heat into the water jacket and would be in favour of economy. But thirdly, supposing the point of ignition to be the same, the indicator diagrams showed, as would be expected, that in test 16 the maximum pressure was reached, and heat was generated, before the piston had begun the expansion stroke. This would tend to reduce the economy due to increased compression. Now it was well known that high compression increased the rapidity of combustion, and enabled mixtures poor in gas to be fired easily. If the piston were in the proper position, the heat rapidly developed

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would be converted into work, instead of being lost or carried away in the jacket water when the ignition was too early, as in test 16. Here therefore the point of ignition was not properly adjusted. Fourthly, not only was the compression increased in test 16, but the ratio of compression volume to the volume at the end of expansion was changed from one-third in test 4 to one-fifth in test 16. This alteration in the expansion ratio must affect the economy; and it was due to the means taken to increase the compression in this design of engine. As would be expected, the indicator diagrams also showed that by the more rapid combustion and greater expansion in test 16 the pressure was reduced before release to nearly half of that in test 4, although the explosion pressure was 280 lbs. per square inch in test 16 and only about 200 lbs. in test 4. It clearly followed that less heat was carried away in unit weight of exhaust gas in test 16; and yet the actual economy was not so good as in test 4. In fact it would be a bold thing to attribute the change in economy in these two tests to the alteration in any one condition, namely compression, when there were several causes co-operating to produce the result. To these various points he had drawn attention in order to show that, in making what would appear to be only one change of condition, a whole train of variables were really altered.

The Report did not mention the number of indicator diagrams taken on one card. Even with steady working, the variation in the diagrams became apparent when they were taken continuously on the same card for say half a minute. A single diagram alone, after a misfire, gave an entirely misleading value of the mean indicated power of a gas engine. It was necessary, he found, not only to count the number of explosions per minute, but also to take the mean pressure during several consecutive explosions. The average of the explosion pressures might easily be obtained from several explosion lines traced on the indicator card as it was slowly drawn under the indicator pencil during half a minute. But with a small engine, such as had here been used, this continuous indicating would considerably reduce the pressure in the cylinder.

Bearing in mind that the limits of accuracy in any result depended on the most inaccurate of the observations, he could not but wonder at the trouble taken by Professor Burstall in reading to one-thousandth of an inch the height of the single indicator diagram, notwithstanding the fact that the variation in the diagrams must have been considerable when the ratio of the actual number of explosions to the maximum possible was only 50 per cent. It would be interesting to know the change in speed of the engine during an experiment under these conditions; and how the area of the piston at the temperature of the explosions was measured. The shape of the indicator diagram might be a guide to the action in the cylinder of such a small engine; but it would be more satisfactory to have the effective or brake power at the same time. A series of several experiments should be recorded, with fuller data for each set of conditions. The timing valve used he thought was not suitable for mixtures poor in gas.

These preliminary results represented much labour lost, without advancing knowledge upon the subject. Fully admitting the difficulty of the problem, he had merely indicated a few points which experience had shown must be borne in mind when experimenting on gas engines.

The President believed there were several other members who wished to speak on this subject; and he therefore adjourned the discussion, to be resumed at the following Meeting.

Mr. Michael Longridge wrote that the torsion indicator constructed from his design about twenty years ago (page 243) had unfortunately been badly made; the piston leaked too much, and the paper slide did not work properly. The arrangement had been mentioned by himself in the discussion upon a paper on indicators which had been read at the Institution of Civil Engineers in 1885 (Proceedings vol. lxxxiii, page 69); the instrument itself had been lost. With a torsion-bar 8 inches long, carrying at one end an arm 3 inches long, he had found that a diagram could be taken as large as those obtained with an ordinary Richards indicator. Such an instrument could evidently be made of larger size, to produce still

(Mr. Michael Longridge.)

larger diagrams with accuracy, because the torsion-bar had so short a radius of gyration and so small a moment of inertia.

Adjourned Discussion, 27 *April* 1898.

Mr. Henry R. J. Burstall, being a member of the Gas-Engine Research Committee, and having been connected with the experiments even before the appointment of the committee, referred to the objects aimed at in prosecuting these experiments. For obtaining information as to the behaviour of gas engines, it had hitherto been necessary to rely on a number of disconnected tests, accurate or otherwise, made sometimes by scientific authorities and sometimes by gas-engine manufacturers; but in most cases carried out under a particular set of conditions only, which, as a general rule, was the best set of conditions for a particular engine working at a particular place. In trying to arrive at any general principles from a set of experiments of that kind, there were found to be practically as many gaps in the information sought as there were data ascertained; and the main object of the present experiments therefore was to fill up as many gaps as possible, and to enable ordinary engineers who were not gas-engine manufacturers to find out what would happen when any particular condition was modified in the working of an engine; and thereby, if an engine was working under certain conditions, to find out what would have to be altered in order to make it work under different conditions. For instance, an engine that he knew of, which had been tested at Kilmarnock with good gas from coal, had been taken over to Belfast and tested with coal gas containing a large admixture of water gas. The performance became then entirely different, and not even the gas-engine manufacturer knew exactly what to do in order to make it work in the most economical way under the altered circumstances. What had been done was to proceed by a method of trial and error, until the engine gave the maximum efficiency. The object of the Committee was to go upon a broader basis, and really to find out and make public the principles governing the variations. Probably some of those principles had already been found out by gas-engine manufacturers, but at any rate they had not yet been published.

In making the arrangements for the experiments, special care had been taken with the whole of the apparatus. An accuracy had been aimed at greater than was necessary in ordinary engineering work. As far as possible the apparatus had been designed to ensure an accuracy more nearly approaching that of apparatus used in a physical laboratory: the reason being that, while the number of tests to be made would evidently be great, the time at the disposal of the reporter was comparatively small. By increasing the accuracy of the apparatus therefore, the duration of the trials was enabled to be so far curtailed that a great number could be made in a reasonable time. During the present college vacation he believed his brother was now making trials at the rate of four a day, which was quick work even for one who had been used to testing engines.

At the last meeting the opinion had been expressed (page 240) that it was impossible by means of an indicator to get a reliable result from a small engine, especially from a small gas-engine, because the indicator cylinder with its inevitable leakage bore too large a proportion to the engine cylinder: the inference being that so much leakage must have occurred through the indicator that the observed consumption of gas was too high. Assuming however that, as in the experiments recorded in the Report, the indicator diagrams were taken every five minutes and the engine was running at 200 revolutions or 100 explosions a minute, it would be found that, even if one whole charge of explosive mixture were lost at every time of indicating, which of course was impossible, there would be an error of only one twenty-fifth of one per cent. As a matter of fact, there was no difference at all. The indicator used had a small capacity, something under one cubic inch, while the engine cylinder had several hundred cubic inches. As to the loss due to the timing valve (page 236), he did not know whether it had yet been measured; but he thought the error thereby caused was of about the same magnitude as that due to the indicator.

(Mr. Henry R. J. Burstall.)

One result, highly important to those who had to test engines, had been worked out: namely the fact that it was possible to determine the actual ratio of air to gas in exactly the same way as it had been possible to determine the quantity of air used in the furnace of a boiler; that is, by analysis of the exhaust gas. If the exhaust gas were accurately sampled and analysed, which was a fairly simple matter, the actual ratio of air to gas could then be calculated with considerable accuracy. To determine the actual ratio, it was not near enough to assume that the gas-engine cylinder was filled with air and gas, as though it were a pump, and thence to calculate the ratio. Such a method involved the further assumption that the temperature at which the air was taken into the cylinder was known. This however was not yet known, though it was hoped that it would be learnt as the experiments went on. It was one of the points to which attention was being directed, because in the small experimental engine the actual quantity of air used was able to be measured, which could not be done with a larger engine, say of 25 horse-power. The ratio of air to gas could be determined, as had been proved by the experiments, by chemical methods which were of quite a simple kind. If the labours of the Committee had proved this only, he thought it was an important step towards accurate gas-engine tests, and also enabled a heat balance to be worked out.

Mr. Bryan Donkin, Member of Council and of the Gas-Engine Research Committee, had seen the experimental engine working originally at King's College and now in Birmingham. The Report now presented would be understood to be only preliminary: it contained only seventeen experiments, and he hoped a much larger number would be made; it included also a full description of all the instruments, and a general outline of the experiments intended, and might be termed a sort of preface to the real work of the research, of which it seemed to him an excellent beginning. Many difficulties and problems he believed had already been solved by Professor Burstall.

From Table 2 it was seen that the indicated horse-power in these seventeen experiments varied from 1·6 to 5·1. The reason for using an engine of no greater power was that experiments could not be made on larger engines. The speed varied from 118 to 204 revolutions per minute. It would be an advantage he thought if the brake horse-power could be added, in order that there might be the data for calculating the mechanical efficiency, which in page 225 was stated to have varied from 76 to 84 per cent., with a mean value of 81 per cent.

The problem of sampling the exhaust gas had been solved by Professor Burstall in a neat way. It was a difficult matter, and had seldom been done well and correctly. It was highly important to get a really representative sample, and particularly over mercury. From the analysis given in Table 2, which showed the percentages by volume, the maximum proportion of carbonic acid in the exhaust gas seemed to be only 9·3 per cent. and the minimum 3·6 per cent.; and the composition determined by analysis appeared to agree fairly well with that arrived at by calculation. Of oxygen there seemed to be almost always a large excess in the exhaust gas. Perhaps in future experiments means might be found of proving whether so large an excess of oxygen was inevitable. Comparing tests 15 and 17, No. 15 showed a thermal efficiency of 21 per cent. with 6·8 per cent. of carbonic acid in the exhaust gas; while in No. 17 the thermal efficiency was 18 per cent. and the carbonic acid 3·6 per cent., or little more than half the volume of carbonic acid for a thermal efficiency only rather lower. Thus the best thermal efficiency was not that which gave the maximum percentage of carbonic acid in the exhaust gas; and he should be glad if some explanation could be offered of this fact.

In Fig. 2, Plate 50, as shown by the dotted lines, it would be seen that a piece of iron forming a junk ring had been put on the inner end of the piston, so as to produce greater compression in some of these seventeen experiments, and by that means the compression was increased so as to range from 52 to 105 lbs. absolute per square inch. More compression seemed generally to mean more economy and higher thermal efficiency; but not always. The speed had not always been maintained uniform, so that it was difficult at present to draw any exact conclusions as to the best

(Mr. Bryan Donkin.)

compression, which of course was an important point, and one the Committee had endeavoured to determine.

With regard to the varying ratio of volume of air to volume of gas, the best result in the experiments was seen to be in test 15, where the ratio was 8·6 volumes of air to one of gas. The proper ratio was an important point to determine in any engine, and no doubt it varied in engines of different sizes and different kinds, single-cylinder or compound. It would be interesting he thought if the ratio of air to gas could be plotted out as a diagram in connection with the thermal efficiency. The temperature of the exhaust gas had not been given in this preliminary report; but he understood it would be noted in future, and also that a heat balance would be worked out for each successive experiment. The thermal efficiency in this small engine was lower than in larger engines, as might be expected for various reasons; the maximum thermal efficiency in the seventeen experiments was 21 per cent. in test 15, which seemed good. For taking the indicator diagrams, the Wayne indicator used was an instrument differing greatly from those generally employed; and the combination of the talc diagram with the rotary-piston indicator seemed a practical plan, and more correct than the ordinary paper diagram with reciprocating-piston indicator.

The temperature of the cylinder walls he was rather disappointed at not seeing recorded in the Report, as this was a matter of much interest and importance, and no doubt had considerable influence on the economy. There were various ways of taking these temperatures, either with mercurial thermometers, or still better by the Callendar thermo-electric method described recently by Professor Callendar in a paper read before the Institution of Civil Engineers (vol. cxxxi, 1897, page 148). By this method Professor Callendar had recently been able with a steam engine, not a gas engine, to take an actual temperature diagram in ink, so as to compare it with the ordinary indicator diagram of pressures and volumes. Professor Burstall also intended, he understood, to go into this important matter of taking the temperature of the cast-iron cylinder walls; and in addition he believed that thermometers had been prepared for taking the temperature of the flame and gas in the clearance space, which was so large a space in gas engines. It was a difficult, tedious, and troublesome undertaking, which however the reporter was fortunately well able to tackle.

For determining the calorific value of the gas during each experiment he thought it would be wise to employ a gas calorimeter. The heating value of the gas he believed had been calculated by the usual analytical methods, by adding up the thermal units due to its several constituents. In a gas calorimeter the gas was burnt in a special burner surrounded by water, and all the heat developed was practically taken up by the surrounding water. Whether in London, Birmingham, or elsewhere, the heating value of gas was found to vary considerably from hour to hour.

Troublesome though the calculation might be, it was important that the proportion should be known which the internal surface cooled by the water jacket surrounding the cylinder bore to the entire area of the internal surface touched by the flame and hot gas inside the cylinder, including the inner end of the piston and the back end of the cylinder. This ratio should be ascertained up to the point at which the exhaust valve opened, namely at about 90 per cent. of the stroke. In a steam engine great difficulty was found in getting 70 per cent. of the total internal surface really steam-jacketed; and he thought that probably the proportion of surface water-jacketed in the experimental gas engine would not be more than 55 or 60 per cent.

Having sent a copy of the Report to four continental friends, all of whom were great authorities on the subject—Professor J. Boulvin of Ghent, M. E. Delamare-Deboutteville of Rouen, Professor A. Slaby of Berlin, and Professor A. Witz of Lille—he had received from them the following remarks, which would be of interest to the members.

Professor J. BOULVIN wrote that he congratulated the reporter upon the precautions taken to avoid errors. It was particularly important to measure accurately the quantity of air for the composition of the charge; the ordinary method of calculating the volume of air admitted was open to serious objection, being based upon the pressure

(Professor J. Boulvin.)

at the end of admission and upon the temperature. The temperature of the mixture at the end of admission was not known; and it was also not probable that this temperature was uniform throughout the whole volume of the cylinder, because at this part of the stroke the mixture was made up of the fresh charge diluted with the remains of the last explosion. The temperature was further influenced by that of the various cavities in the cylinder walls with which the charge came in contact. In a series of experiments made by himself in 1893, with an object similar to the present, the composition of the charge had been varied by regulating the quantity of gas by means of a conical inlet, while the quantity of air was kept always constant. The number of revolutions per minute and the number of explosions per minute were kept as constant as possible, and the trials were made at full power, the brake being loaded to give only two or three misfires per minute. The engine was a Stockport gas-engine with Otto cycle, producing from 5 to 6 brake horse-power as a maximum at a speed of from 188 to 195 revolutions per minute, with tube ignition and without timing valve. On reducing the volume of gas relatively to that of air, the latter remaining constant, the power exerted was observed to diminish regularly, while the consumption of gas per brake horse-power increased regularly, as shown by the following figures:—

Revolutions per minute	195⅓	188	190
Explosions per minute	93·7	92·2	92·2
Outlet temperature Fahr. of circulating jacket-water, entering at 72° Fahr.	192·7°	195·8°	201·2°
Brake horse-power	5·69	5·14	4·92
Cubic feet of gas per B.H.P. per hour . .	28·61	30·02	30·73
Cubic inches of gas per explosion . . .	50·04	48·21	47·60

During the trials of this engine, which were repeated many times, it was found that the temperature of the jacket water had a great influence on the economy. In other experiments he had found that the oiling of the cylinder also affected the results considerably. In any experiments therefore with a view to discover the influence of a single factor, he concluded it was essential to keep the temperature of the jacket water constant, and also to maintain the oiling of the piston uniform. It appeared desirable further to maintain the maximum number of explosions, because any cycle without an explosion produced great disorder in the thermal conditions of the cylinder, and also in the composition of the charge which followed the misfire.

M. E. Delamare-Deboutteville wrote that, as experiments had not yet been made at full load, the maximum economy of the engine had not yet been ascertained; and he looked forwards therefore to a future report for more experiments on the same engine at full load. Moreover in the table of results the indicated horse-power only was recorded, and not the brake horse-power; whereas the latter was the more important of the two. Only a tube igniter he noticed was used; instead of this he believed the only way to ensure certainty of explosion was to use electric ignition, applying the spark in the slide-valve, as had been done by himself. A signal service he considered would be rendered to science and industry by this research, if it could be proved what was the best degree of compression with a given ratio of air to gas, in a gas engine of given size, make, and power, working always at three-quarters of its full power and at a constant speed.

Professor A. Slaby wrote that, having read with great attention the first Report to the Gas-Engine Research Committee, he thought these would be the most complete and accurate researches yet made on a gas engine. The method of measuring the volume of the gas by a calibrated bell was better than that which he had himself adopted. The new indicator for taking diagrams was highly interesting, and he looked forwards to learning the result of further tests made with it, which he hoped would be published. The great scientific accuracy aimed at by Professor Burstall would doubtless result in valuable work being accomplished. There were two matters which he regretted. The first was that the metric system was not used for recording the experimental results, so that comparisons might be made easily with foreign tests; science was international, and should speak everywhere by means of the same

(Professor A. Slaby.)

measures and formulæ. The second matter of regret was that the heating values given of the gas seemed to be calculated from the chemical analyses. This method did not correspond with the standard of accuracy set up for the rest of the research. In his opinion it was not the best plan, and he considered the heating value should be determined in each experiment by means of a gas calorimeter; the best he thought was the Junkers. He was himself about to make some fresh experiments on a 4-horse-power gas engine, and he hoped his researches would agree with those of Professor Burstall.

Professor A. WITZ wrote that the experiments described in the Report appeared to him to be so well arranged as to be quite a model of their kind. To the table of results it would be well if the pressure could be added of the gas on its admission into the cylinder; and also the temperature of the exhaust gas at the moment of its discharge from the cylinder, in order that the quantity of heat carried off in it might be known. Judging from his own experiments, he rather feared the anticipations of the Committee might not be fully realized by the analytical method they were following, which consisted in varying the several working conditions of a small gas engine—namely compression, speed, number of explosions per minute, ratio of air to gas, &c. This method hardly allowed of determining the conditions necessary for the most economical working; for another engine they might be different, and might also vary with a gas of different composition. In this respect gas engines were essentially different from steam engines. Preferably he should himself have proceeded by the synthetic method, notwithstanding that it might not seem so practical as that adopted. Theory derived from simple laboratory experiments allowed of formulating certain laws, such as had been arrived at by Mr. Dugald Clerk, Professors Ayrton and Perry, Mr. Grover, Mr. Salanson, and himself, relating to the action of the cylinder walls and to the speed of expansion. Although these laws had been verified in certain instances for individual engines and for a particular gas, they were not correct for other conditions. The object of the present research he considered should be to discover when and where they ceased to hold good; the field would thus be narrowed, and there would be a better chance of arriving at a satisfactory conclusion. The problem was one of such great difficulty that there was no certainty of solving it even with patient investigation; but he hoped such a result would ultimately be achieved. A theory assumed as a basis to start from ought to be verified not with a single engine but with several, and under the various conditions occurring in practice. The object was to discover the best conditions for enabling a gas engine to produce the maximum work per heat unit.

Professor David S. Capper thought there was some difficulty in criticising the present Report, in consequence of its giving preliminary results only; and it was perhaps on this account that the criticisms at the previous meeting had seemed to himself so disappointing. Those criticisms appeared to him to amount only to a statement of the difficulty of the problem, and to a complaint that, although the reporter had tried to simplify it, he had not really succeeded in doing so. The old Scotch proverb that "Fules and bairns should not see things half done" seemed to him to be applicable to such criticism of preliminary experiments, which had been reported by Professor Burstall while as yet he was only on the threshold of the investigation. No definite conclusions could be drawn from the experiments here recorded, which must be examined simply in relation to preliminary work, namely the calibration of the instruments and the engine, and the determination of the probable experimental errors. In this respect he thought an admirable example had been shown. Having had the pleasure of being present at a good many of the calibrations, he could say that the instruments had been calibrated with a care equal to that expended upon any physical experiments of which there was a record. The trials here reported had been carried out with London gas in his own laboratory at King's College. The results so far obtained seemed to him to be highly suggestive, but at present the suggested interpretation of them could not be regarded as conclusive, pending the further and wider range of experiments which were now being entered upon. There was one fact which seemed to be clearly established by these preliminary experiments, namely that the ratio of air to gas in the charge used in a gas engine could be determined with close accuracy by calculation from exhaust analysis. The method of calculating the air used in a gas engine on the assumption that the cylinder and clearance of the engine were filled with air and gas at an assumed temperature (page 225) he considered was not necessarily wrong. If the clearance space were assumed to be filled with exhaust products and air in a proportion depending upon the ratio of explosions to cut-outs by the governor, and if the cylinder were calculated as filled with gas and air, a result was obtained agreeing closely with that derived from exhaust analysis. Having himself made some experiments upon this point with a gas engine, he had found that the discrepancy which seemed to occur generally, as pointed out in page 225 of the Report, arose from the assumption usually made that the clearance was filled with the live mixture, instead of with more or less inert products. The calculation referred to in page 225, which came out about 15 per cent. too large, had been obtained he believed without taking into account the inert gas remaining in the clearance space at the end of the explosive stroke. In a careful experiment he had carried out upon a Crossley gas engine of about 11 brake horse-power, he had found that, after allowing for the inert gas in the clearance space, he got a ratio of air to gas of 7·27 to 1. From the exhaust analysis, which had been made by Mr. Huntly in precisely the same way, although perhaps not with quite such accurate apparatus, as that described in the Report, the ratio of air to gas was determined as 6·9 to 1. Here therefore the error was only a trifle over 5 per cent., which, on comparing the columns showing the composition of exhaust gas by analysis and by calculation in Table 2, appeared to be an error, or amount of variation from the results obtained by direct air-measurement, that occurred even in the accurately determined experiments here recorded. In this respect he was glad to find that the experiments hitherto carried out had not been wasted, although exhaust analysis was much the better method. The ratio obtained by the old method however, if calculated properly by allowing for the inert gas, seemed to be correct within about 5 per cent., which in most gas-engine experiments was a reasonable degree of accuracy.

With regard to the indicator diagrams, he thought sufficient attention had not been drawn to the ingenious plan of taking the diagrams upon smoked mica. The diagrams obtained in that way would be highly appreciated by all who had hitherto worked with pencil or metal pointers on ordinary paper. The ease and accuracy with which any measurements of pressure could be made upon the mica within a minute range was remarkable and highly satisfactory. It was indeed a most ingenious invention, which he thought ought to receive wide-spread recognition. With the reporter's criticism of the Wayne indicator (pages 218–20) he entirely agreed.

Professor Alexander B. W. Kennedy, Past-President, Chairman of the Gas-Engine Research Committee, having expressed his views at the outset of the previous discussion (page 230), would now only add that the object of the presentation of this first Report had been correctly interpreted by Professor Capper. The work which had thus far been carried out for the Committee had been in hand a long time, and had caused the reporter a vast amount of trouble. The choice had lain between either leaving the record of all this preliminary work to stand over for perhaps a good many months, and then giving it to the members after some further and more elaborate work had been accomplished, which would include the temperatures, heat balance, and other results; or else giving the present information in the first instance as a preliminary Report, showing the nature of the work and of the appliances for carrying it on. The latter had been thought by the Committee to be the best course, and they had therefore laid this first Report before the members; he was glad they had done so, because he thought the Report was quite capable of standing on its own feet so far as it went. Later experiments, as had been indicated in the Report and as was quite understood, would go much further, could be more systematically carried out, and could have their results more completely measured, because the apparatus was now entirely ready. He adhered to the opinion he had previously

(Professor Alexander B. W. Kennedy.)

expressed, that the work of the Gas-Engine Research Committee would be by no means the least scientific or the least practically useful of any of the research work carried out by the Institution.

Professor **Burstall**, in explanation of the reason why there were not more tests included in the present Report, pointed out that, when the engine and apparatus had been completed and had just been got into running order at King's College, he had himself had to remove from London to Birmingham. Under those conditions there had been no alternative but to carry out the experiments on Saturdays by coming to London from time to time on the previous day. It would therefore be readily understood that the experiments had to be carried out irrespective of everything which might have involved delay; and a great number of the conditions which were varied were varied not intentionally, but simply because it could not be avoided. For example, the low-speed tests had been rendered compulsory because the water motor which drove the fan for the air supply was connected to the mains, and at that particular time the mains would not give pressure enough to drive the fan fast enough for higher speeds of the gas engine. After the engine and apparatus had been removed to Birmingham, it had to be wholly re-erected; and in course of transit a certain amount of damage had happened, which had to be repaired. For this reason the number of tests had been much more limited than it would have been, had the apparatus been in one place during the whole time.

As one of the authorities on gas-engine construction, Mr. Clerk (page 234) was naturally one of those who would be looked to for a wide and general criticism on all work of this kind. A number of conditions had been laid down by him, which would doubtless be highly interesting to gas-engine manufacturers; and he had pointed out what a gas engine should not be. He had not indicated however the directions in which this particular experimental gas-engine was deficient from his own point of view, beyond stating (page 235) that the addition of a junk ring on the rear end of the piston was essentially bad. Naturally the use of a junk ring to produce an increase of compression was not the method that would be employed if an engine were designed for working with high compression alone; and it was admitted by Mr. Clerk (page 236) that an engine to work under different conditions of compression, and at the same time to give the highest possible economy at each compression, would not be easy to construct. In the engine used for these experiments the surface of the clearance space was the minimum possible; and had the whole increase of compression been produced by pushing the cylinder liner further in, the valves would have had to be placed in separate valve-boxes, which would have increased the surface of the clearance space. There was evidence in Table 2 that the use of the junk ring did not greatly affect the thermal efficiency, because in test 3 no junk ring was used, the compression being produced by inserting packing pieces in the connecting-rod head; while in test 5 the junk ring was used, and the packing pieces were taken out. Here the compression and the ratio of air to gas were seen to be nearly the same, the speed alone having been altered; and the thermal efficiencies were 15·5 per cent. in test 3 and 15·6 per cent. in test 5.

In Mr. Clerk's statement of ten to one as the best ratio of air to gas (page 237) no idea was given as to how his figures had been obtained. Unless the air were measured, or a careful analysis were made of the exhaust gas, it was not possible to find the ratio. With London gas a mixture in the ratio of ten to one was not easy to burn completely.

It seemed as though it were considered (page 240) that the experiments showed the economy to be worse at high compression; but the results in Table 2 showed that the maximum economy was at the highest compression, and in all the more recent experiments which he had since made it had been found that an increase of economy was produced by an increase of compression if a suitable mixture was used, but that the mixture which was best at a low compression was not best at a high compression.

As to the use of an indicator on such a small engine being detrimental to economy (page 236), he had examined carefully the whole of the published researches on gas engines, and had not found, even in the laborious and exact researches of Professor Slaby, any

(Professor Burstall.)

mention whatever of such an error, although Professor Slaby himself had used a gas engine having a cylinder of only 6·3 inches diameter with a stroke of 13 inches. Moreover he believed it had never before been considered that any appreciable quantity of exhaust product could be discharged by leakage through the indicator. In order however to test the question practically, he had kept the gas engine running for ten minutes without the indicator, and had read the brake load and the gas consumption. Then he had turned the indicator on for the whole time during a further ten minutes, and had repeated the readings; and he had been unable to detect any fluctuation, either in the brake reading or in the gas consumption: the real reason being, as pointed out by his brother (page 249), that the contents of the indicator were so extremely small in comparison with the volume of the engine cylinder.

The use of a timing valve however (page 236) he was rather inclined to consider was not in itself an advantage. An open igniting tube was no doubt quite satisfactory for ordinary working; but in making tests there was too much variation in the indicator diagrams to allow of any accurate conclusions being drawn from the results. Many tests had been made with the open igniting tube; but the results were not good, owing to the variation which occurred in the size of the diagrams, however carefully the height of the heating flame on the outside of the tube was regulated. It was for this reason alone that a timing valve had been added. Any error on the timing valve however he thought was not of serious moment; at least he had not been able to discover any discrepancy between the experiments carried out with an open ignition-tube and those with a closed tube.

The simile suggested by Mr. Atkinson's humorous story of the early steamboat (page 240) would not apply to the experimental gas-engine, because the latter would run at full speed and full compression with the indicator open all the time, which was quite satisfactory. The indicator diagram shown in Fig. 26, Plate 60, representing fifty consecutive explosions by a porcelain ignition-tube with 100 lbs. compression (page 241), did not in his opinion alter the statement made in page 224 about the porcelain ignition-tubes not igniting so promptly as iron tubes. Compression to 100 lbs. and an initial pressure of about 320 lbs. per square inch, as shown in Fig. 26, meant that the ratio of air to gas was low, probably not more than 7 or 8 to 1. With so rich a charge and such high compression there was no difficulty in igniting; the difficulty would be to avoid igniting. Any tube would ignite a charge like that, whatever material it was made of, if it was only moderately hot The difficulty was to ignite weak charges at low compression. From the experiments made on other engines he was satisfied that an iron tube was the best of all for ignition, even though it was awkward in other respects.

Though not mentioned in the Report, the readings of the barometer (page 243) had been taken; and moreover the cubic feet of gas consumed had been corrected for pressure and temperature in all the experiments. The observed results had been corrected to 760 millimetres or 29·92 inches of mercury, and 15° centigrade or 59° Fahr. The duration of each test was half an hour, which he considered was three times as long as was absolutely necessary. Ten minutes' tests were quite long enough on an engine of this kind, because everything was here perfectly steady. The Junkers calorimeter (page 243) was a useful instrument where the gas was being drawn direct from the mains; but in these experiments the gas was taken from the main into a gas-holder, and therefore was identical in quality and composition throughout a series of tests. A sample of the gas was taken out of the gas-holder, and analysed for the series. Therefore a Junkers calorimeter would here be unnecessary, as the gas analysis would have to be carried out in any case.

In Mr. Robinson's comparison (page 244) of tests 4 and 16, conclusions had been drawn with which he could not agree. For example, the amount of heat rejected through the jacket was 32·8 per cent. in test 16 with the smaller clearance, Table 2, and 41·5 per cent. in test 4 with the larger clearance: which did not show that the clearance surface was responsible for the lower economy in test 16. The change in the ratio of expansion was caused by the change of compression. The engine was not forced in test 16, for it

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missed 30 per cent. of its charges and gave the thermal efficiency of 13·4 per cent.; whereas in test 17, where only 15 per cent. of the charges were missed, a thermal efficiency of 18·0 per cent. was the result. A comparison of test 2 with test 17 showed the gain produced by the higher compression in the latter. The ratio of air to gas he considered in both tests 4 and 16 was too low, namely 7·13 and 7·18 respectively; a weaker mixture was desirable in both.

The inference was mistaken (page 247) that he had measured an indicator diagram to one-thousandth of an inch. What had been done to this degree of nicety was to measure the calibrations of the indicator spring, as described in page 221; and this had been done only because doubt had been expressed at the time as to whether in any spring the ratio of movement to resistance truly followed a straight line throughout the extent of its range; he had therefore read the indications 'as accurately as he possibly could.

The excess of oxygen found in the exhaust gas of the more economical tests, with the consequent lower proportion of carbonic acid (page 251), was explained by the fact that the richer charges produced too high an initial temperature, which could not be properly utilized owing to the cooling action of the walls. The experiments could not well be plotted in diagram form so as to show the influence that the ratio of air to gas had upon the thermal efficiency (page 252), because in order to do this it would be necessary to assume that all the other factors remained constant while the ratio of air to gas was alone varied. The idea of ascertaining the amount of internal surface which was jacketed (page 253) was good, as this information would throw light upon the amount of heat rejected through the walls. It would be given in a future report.

The President moved a vote of thanks to Professor Burstall for the highly interesting Report which he had now presented to the Institution.

Mr. John Fielding, member of the Gas-Engine Research Committee, wrote that the conclusion arrived at in the Report, as to gas-engine economy depending mainly upon the correct ratio of air to gas, confirmed his own experience in relation to some recent engines of large size, built specially for electric lighting. The main stipulation with which these engines had to conform was that under all conditions of load the cyclical variation in speed should not exceed that corresponding with one half of a volt above or below the nominal. In his opinion the best way to obtain this result was to abandon altogether governing by the "hit and miss" or cut-out plan, and to fire a charge in every cycle, the volume of the charge being regulated by the governor. Notwithstanding that all records of previous attempts to govern in this manner were of a most discouraging nature, this was the plan he had adopted. The air and gas inlets were fitted with throttle-valves, specially arranged so that the proper adjustment of the ratio of air to gas for the full load might be made without disturbing that for the light load. One advantage of this arrangement was that the light charges, which had to be fired at low compression, might be of a somewhat richer composition than the heavier charges, for which the compression was higher. Whilst he had expected and obtained the most satisfactory results as regarded regularity of speed, inasmuch as the main stipulation had been fully met, his fear that the light-load consumption would be unfavourable had proved to be unfounded, the results showing a slightly better light-load economy than that stipulated for. The records of earlier attempts to govern by throttling, notably in the Griffin engine, showed that it was carried out only from full load down to about half load, below which the charges were cut out, on account he believed of the risk of misfires. With the engines he had recently constructed, his experience showed that it was perfectly practicable to fire every charge from full load down to no load; and this he attributed, amongst other causes, to the provision for making the charges slightly richer at light load and no load. The advantage of this plan was well seen from the indicator diagrams, which maintained the same characteristic form at all loads, and showed

(Mr. John Fielding.)

accurate timing of ignition, the only difference being in their height. He therefore ventured to suggest the desirability of making trials with the experimental engine on similar lines—namely by governing absolutely without cut-out, from full load down to no load—with a view to demonstrating accurately what loss of economy, if any, was incurred thereby, in comparison with governing by cut-out and employing charges of constant volume and composition. The results he thought would be extremely interesting and of great value in relation to gas engines for electric lighting. As a gas-engine builder he considered the Institution and the Research Committee were to be heartily congratulated upon having secured so able and scrupulously accurate an experimenter as Professor Burstall, whose first Report warranted the anticipation that highly valuable information would be obtained for the guidance of all concerned in the construction and working of gas engines.

Professor Burstall wrote that as to the importance of keeping the temperature of the jacket water constant he quite agreed with Professor Boulvin (page 254). The results given by Professor Boulvin showed a loss of economy with the weaker charges; without the indicator diagrams it was difficult to compare the three experiments, as the loss of economy might be due either to the ignition being too late, or to a reduction in the weight of the charge, caused by the increase in the temperature of the jacket.

The method of electric ignition employed by M. Delamare-Deboutteville (page 255) had been tried, but without success; probably because the engine could not be adapted to this method of ignition.

In a future report he would endeavour to meet Professor Slaby's wish (page 255) by giving results in both the metric and the English measurements. As regarded defect in deducing the heating value of gas from a chemical analysis, Professor Slaby was doubtless alluding to the uncertain nature of the heavy hydrocarbons taken as C_3H_6 in page 224. It was possible to determine the heating value by a method which Professor Slaby had himself indicated (Calorimetrische

Untersuchungen über den Kreis-prozess der Gas-maschine, page 6); this method had not been used, owing to lack of certain data in the gas analysis, which could not at that time be obtained.

It was interesting to find that Mr. Fielding (page 265) had obtained results which showed the importance of increasing the richness of the charge at low compression. If possible a set of experiments would be made on the engine from light load to full load without missing any explosions, by altering the amounts both of air and of gas, as had been done by Mr. Fielding, instead of cutting out any charges. The results would then furnish a direct comparison of the economy attending the two methods of governing.

STEAM LAUNDRY MACHINERY.

BY MR. SIDNEY TEBBUTT, OF LEAMINGTON.

Introductory.—Until only a few years ago, with one or two well-known exceptions, no engineers undertook such work as Steam Laundry Machinery; whereas at present there are a considerable number who pay special attention to it, and some who do hardly any other class of work. The French, if not actually the pioneers, were early in the field; but it is almost entirely from the United States that the present style of machines has come. Articles received at laundries for cleaning are of the greatest diversity as regards quality, shape, age, size, and material; and even the strongest have only slight cohesive strength. They come in all sorts of condition; some hardly require cleaning at all, while others are so soiled that it would appear to be almost impossible to clean them. As the same articles come over and over again, the machinery for treating them must be carefully constructed to provide against their wear and tear. Also it must be able to stand constantly changing conditions of wet and dry, and of heat and cold; and it must be extremely simple, because the persons using it are mostly girls, often young and untrained. For these reasons it is obvious that it should be of first-class and suitable material, and be well constructed. Provision should also be made for speedy repairs or renewals, inasmuch as long stoppages are most injurious to business.

Arrangement of Laundry.—A well arranged laundry will generally consist of two long sheds or bays, running side by side and separated by a partition. At the entrance there is a space for hampers, and then comes the sorting room, followed by the washhouse, the store-room, and the drying room, which together occupy one bay to the far end. Returning along the other side of the partition, at the far end comes the ironing or finishing room, then the airing room, and lastly the packing room, which adjoins the entrance. The office comes between the sorting and packing rooms. Goods thus arrive and leave at the same place; and in the entrance passage the packed hampers can be stored in readiness to be taken away by the vans.

Laundry machinery can be broadly divided into that which cleanses and that which finishes.

Cleansing Machinery.—It is to be noted that all heating of the washing liquors is done by turning steam into them direct. On this account the steam must be clean, and free from grease and other impurities, or else the latter will get into the clothes. The large quantity of steam required necessitates relatively large boiler power; but the amount varies so much at different times that mechanical stoking would seem to be unsuitable. Probably the best form of boiler is the modern Lancashire. Inasmuch as a boiler and consequently an attendant are necessary, it will be understood that an ordinary steam-engine is the most economical motor for furnishing the power required. The power needed is small; a 9-inch cylinder engine of ordinary make, running at 60 revolutions a minute, is sufficient for all except the largest laundries. [See page 299.] If exhaust-steam injection is employed for feeding the boiler, care must be taken to avoid the introduction of grease, by the use of a minimum quantity for lubrication, and by freeing the exhaust steam from the lubricating material before it reaches the exhaust injector. Where so much heat is needed in working all the year round, it appears advisable to utilise the exhaust steam not for warming the building in cold weather, but rather for some constant requirement in all seasons.

Water Softening.—Whatever apparatus is used must be of the utmost simplicity; it may require fairly constant attention, so long as the attention is of a simple nature. Except in particular instances, all laundries should have a water-softening apparatus. Quite apart from the other advantages that are obtained from the use of soft water, the actual saving in washing materials is considerable.

Piping.—Whether for steam or water, the piping and fittings commonly used are seldom found to be tight, or right in other respects; and loss is constantly taking place, which although continuous is not readily noticed. It is highly important that the piping should be arranged to be got at with ease, and without undue disturbance of the working of the laundry. The water pipes are liable to fur up, and the steam connections or fittings to become leaky; both therefore may require frequent attention. The water pipes are seldom large enough. A washing machine such as is in common use should be supplied by a water pipe of not less than $1\frac{1}{4}$ inch bore. Such pipes should be of copper, and should have unions at all branch points for taking apart to clean; the position of the unions is important. As there is only at most a few feet head of water pressure, the copper pipes may be thin; a thickness of No. 19 to 20 B.W.G. or 0·040 to 0·036 inch will do perfectly well; and if plenty of unions are inserted in the long lengths, thin piping can be easily handled without injury. Where thick pipes are used, or such as are cut with circular cutters in fitting them up, all ends should have their inside burrs filed off after cutting. Another important matter is the construction of the bends and tees, and of the taps or cocks which are usually made with too small waterways. If these are supplied by an ordinary coppersmith, it will probably be found that $1\frac{1}{4}$-inch piping will not deliver more than an inch pipe running full bore, and often much less. Specially is this the case in regard to cocks or valves. A good plan is to have all these fittings of a size larger than is necessary to put on the outside of the ends of the pipe, and then the waterway will be found to be about right. No threading will in this case be required, the joints being soldered. The steam pipes can be made of ordinary wrought-iron steam piping; or of galvanized iron of the kind used for water, unless a high pressure is used, which is not advisable; 60 to 70 lbs. per square inch is quite high enough. It is advisable not to have less than half-inch steam piping anywhere; and a half-inch pipe into each end of the washing machine, leading out of a $\frac{3}{4}$-inch pipe, will be sufficient. The valves have such constant wear that re-grinding and renewal are required at frequent intervals; and therefore the piping should be so arranged as to be easily got at, and the junctions at the main pipes should be well made with brass unions ground in. The whole of the piping should be carefully designed and the fittings well chosen, because these play a highly important part in steam laundries, and it must be remembered that they are not used with care. Few parts fail more than the piping. Under certain conditions armoured hose piping has been successfully adopted. Lever throughway valves for water may be used in some cases; but if screwdown valves are adopted, the valves themselves should be of leather.

Pulleys.—Where a fan is properly arranged for carrying off steam, wood pulleys can be used without any injury to themselves from dampness, and without any difficulty in the belts obtaining proper grip for driving the machines.

Washing.—A common method of washing is first to soak the linen as long as possible, up to 24 hours, in soft water having a little soda in it, at a temperature of about 70° Fahr. Then wash with soap and soda solution for twenty to thirty minutes in soft water warmed to about 100°. After letting this liquor run away for say five minutes, wash a second time in a fresh soap and soda solution, the same as the first, only somewhat hotter, raising it up to say 130° before finishing with it. A third similar liquor is used for boiling. It is important that just enough soap and soda should be used to keep a good lather during these operations; but not too much, for if it be frothy, the subsequent washing is not so well effected. A run of twenty minutes is sufficient after the boiling point has been attained. After this, rinse in two or more lots of water, to the last of which the necessary blue colouring is added. This process can obviously be modified greatly in many ways and under varying conditions. Soaking may be done in separate appliances, as may also rinsing and blueing. Some goods do not require a second wash, while others need two short washes only. If soaking is done in the washing machine, only ten minutes should be allowed for it, and the soaking liquor may be used for the first washing. If all the operations are done in one machine, from 2½ to 3 hours will be required for linen that is ordinarily soiled. There are also other methods of washing, though not commonly used.

Washing Machines.—The kind of washing machines required depends largely upon which of the three plans of cleansing that are in general use is adopted. The first plan is to use two washing machines for the actual process of washing alone, leaving the soaking, boiling, rinsing, and blueing, to be done by separate appliances. The second is to perform in a single machine all the processes of chemically acting on the dirt and clearing it away. The third plan is the same as the second, except that the boiling, which in the first and second plans is done at atmospheric pressure, is done in the third under steam pressure up to 10 lbs. per square inch or 239° Fahr. For the first process, washing machines with their main parts constructed of wood may be used with advantage, because satisfactory machines for this process can be constructed of wood at a low cost, inasmuch as the heat required for the washing proper, say up to 130° Fahr., does not seriously injure some kinds of wood. For the second process the machines should be made entirely of metal, because the boiling acts rapidly on nearly all sorts of wood, and soon pulps it. In some of these machines both wood and metal are employed in combination; but except for cheapness there is no apparent advantage in combining the two materials; and the renewal of the wood is always troublesome. The third process demands still more urgently that the whole of the machine should be made of metal; and in order to hold steam at pressure an entirely different and more costly design of machine is required.

Washing machines are perhaps the most important of all the appliances in a steam laundry; there is a large variety, of which those only that represent the commonest designs need be considered. The method of washing by the action of beaters upon the fabric, as in the dolly machine, is useless, except for tent cloths and similar heavy material, unless the condition of the material after washing is a matter of indifference. There are also machines which act by continually squeezing small masses of clothes, as illustrated in Fig. 1, Plate 61; and this mode of action may be useful under certain conditions. But 90 per cent. of the washing machines in use act by continually lifting the clothes a certain height out of the water, and then allowing them to fall into it again. Obviously a strong washing action can be obtained by allowing a sufficient fall; and the action in any one machine can easily be regulated within limits by filling it with more or less water, and thus altering the height of the fall. This commonest form of machine, illustrated in Figs. 4 and 5, has an outer cylindrical casing fastened to circular discs for its ends; and inside the casing, which is stationary, revolves another cylinder or cage, in which the clothes are placed. Between the insides of the two cylinders there is communication for liquids through holes made in the metal or wood forming the inner revolving cylinder. The direction of revolution of the latter is continually reversed. The reversing action is usually obtained by two belts, and the number of revolutions each way varies from three to five, according to the maker's experience. This kind of machine came from America, and the revolving cage is usually made about three feet diameter. The striking gear, which is mostly copied from the American original, is in some instances ingenious. A machine which has had a fair amount of success is illustrated in Figs. 2 and 3, giving a longitudinal or end motion to the contents in turning them over; but its action is too mild, although it does well for flannel washing.

It is most important to provide against any possible iron-mould or rust. Where the machine is of wood this is difficult, because it seems impossible to keep iron bolts in order; and brass bolts are not at all satisfactory. Experience seems to show that, where galvanized iron comes in contact with wood in the presence of water, sooner or later the oxidation will eat through the zinc. The best plan is to fasten the wood together with brass wood-screws. The use of brass wood-screws also enables all internal projections to be easily avoided, which in some instances is no easy matter. Indeed most machines are faulty as regards the interior surface of the revolving cage, often owing to the lifter fastenings or the door fastenings. The door is a prolific source of trouble. If the fabric that is being washed can manage to squeeze itself into any space between the door and the body of the cage, cuts will at once be made in the fabric when the cage is made of metal. Sliding doors, as shown in Figs. 6 to 8, Plate 61, generally avoid this danger entirely. Teak is probably the best wood for cages. In order to avoid wear to the clothes in metal cages, a plan of countersinking the holes in the cage by bending the sheet metal outwards at the holes has been adopted in America. Where the holes are situated so that the clothes will rub against them, the plan is commendable.

Lifters.—For gripping the clothes and helping to lift them, pieces of wood or metal are fixed longitudinally along the inside of the cage, as shown in Fig. 5, Plate 61. Wood lifters are sometimes preferred; but except that it gives perhaps a better grip there is no apparent reason for using this material, and brass never wears out. The American machines are behindhand in the matter of the best form of lifters, and seem to indicate a failure to realise what is required. The effect of the lifters, such as are used in the American machines and largely adopted in the English, is to roll the clothes round; and the reversing motion of the cage is powerless to prevent this from taking place to such a degree that in some laundries the clothes become a tangled mass, which has to be lifted bodily out of the machine and to be separated by hand, or, if not so bad as this, yet requiring the utmost care to unravel. Even if they have not been torn in the machine, tearing can hardly be avoided in the unravelling. A cage can be constructed, and is in use, which so slightly "ropes" (as this matting together is called), that the clothes come apart with the utmost ease; this result is accomplished by employing a judicious form of internal projections or real lifters, and a right number of them, properly arranged. In Figs. 9 to 12, Plate 62, are shown three plans of such lifters, which do not act as rubbers. Lifter A is made of brass tubes, which however are difficult to fasten securely at the ends, and are liable to let clothes get between them and to cause injury to the fabric. Lifter B presents the objection of projecting rivets and edges, against which the clothes become injured; also the holes for the water cannot here be made close to the corners of the lifters, where they should be. Lifter C fulfils all conditions required, the bolt heads and edges being all kept inside it. If made with open ends, these lifters can be used for carrying water up and causing it to run out upon the clothes lifted; but this is inadvisable for other reasons.

In Fig. 17, Plate 63, is shown a washing machine having only a single cage, which is watertight, and into which the washing liquid and clothes are placed. This single-cage form of rotary machine has nearly gone out of use, except for hand machines. The particular section here shown has been used in Germany for many years by the inventor, and is interesting as showing that lifters are no new idea.

Speed of Revolution.—The greater the speed, the higher the clothes will be lifted before falling, unless they be carried right round or beyond the top centre; but the author believes they undergo more wear and tear at the higher speed, although he hardly knows why. Some machines are run at thirty revolutions per minute; but this he considers is much too fast; twenty-five should be an outside speed, and to some users twenty would appear to be fast enough. The object is to give the greatest practicable height of fall to the clothes. If only a small depth of water is used, the clothes fall largely upon the sides of the cage, which moving rapidly are sure to cause wear and tear. The clothes should fall into the water, clear of the cage. A sufficiently full fall may be taken to be when the clothes drop from the cage at about 30° above the horizontal axis, or 60° before reaching the zenith, so that the forward motion shall not carry them beyond the centre of the cage during their fall. But as no machine has been constructed in which the whole internal action can be observed while at work, the details of what actually takes place inside the cage are not yet clearly ascertained. The amount of clothes which can be treated at one charge, in a revolving cage of say 3 feet internal diameter and 3½ feet long, is considerable; measuring by a common laundry standard, 250 shirts can be satisfactorily treated at one charge, weighing about 180 lbs. when dry, and 250 lbs. after centrifugal drying.

Circulating action.—The supply of steam and water and liquor should be introduced into both ends of the machine at the same time; and the soap and soda, which should always be kept in solution, should be added while the machine is in motion, by an arrangement specially constructed for this purpose. Endeavours have of late years been made to add some arrangement for producing a circulation of the washing liquor while the machine is working, so that it may be continually passing from the outer casing into the revolving cage, and round again into the outer casing. Some of the plans are ingenious and valuable. Two are illustrated in Figs. 4 and 5, Plate 61, and in Figs. 13 and 14, Plate 62. That shown in Figs. 4 and 5 is constructively good; it delivers the water into the cage in the centre of the ends, where there is no resistance due to the water and clothes; whereas in the plan shown in Figs. 13 and 14 the water has largely to be forced into the cylinder. Although machines will do good work without such an arrangement of central delivery, it is a distinct advantage, and should be adopted, unless some disadvantage is found to arise from its use. When designing a machine, the difficulty of cleaning it should be kept in view. For this reason, and also for ease of putting the clothes in and taking them out, the door of the revolving cage, as well as that of the outer casing, should be the full length of the machine where possible. There should be fitted to each machine a gauge-glass, which in the absence of steam pressure need not have its upper end closed. In Figs. 15 and 16 is shown a plan that has been adopted for circulating the water lying at the bottom of the casing of a washing machine. Upon the outside of the revolving cage are riveted helically strips of angle-iron about 1 inch by 1 inch, which act like a quick screw or rifling. They also help to stiffen the cage, and enable thinner sheet-metal to be used for it.

Use of Steam Pressure.—Most of the foregoing remarks apply equally to machines working with steam pressure, which however is used only in the process of boiling; but in these it should be noted that the door cannot be made large, and that in nearly all respects the design will be different from that adopted where no steam pressure is used. As a rule, machines which work under pressure are made with a cage of larger diameter, although shorter in length; and they often have a central longitudinal partition throughout the length of the cage, dividing it into two semi-circles, as shown in Fig. 19, Plate 63. This plan has the advantage that the axle can here be formed by a shaft running right through from end to end, which is constructively good, especially where the cage is of considerable weight. It has the disadvantage however of requiring two doors in the cage, one for each compartment. In all respects machines working with steam pressure are much more expensive, and more difficult to clean, and the attendants should be men; which is not the case where steam pressure is not used. The advantages claimed for the employment of steam pressure are that the machines wash better, produce a better colour in the clothes, and also thoroughly disinfect the articles washed. These are important points, and if realised in practice should lead to the adoption of steam pressure in nearly all instances, particularly where the necessary capital and space are available, in spite of the fact that the steam-pressure machines may be rather more costly to handle. As to their superior washing powers, it is difficult to speak with any certainty; for while some users are decidedly in their favour, others maintain that equally good results are obtained without the steam pressure, and with consequent freedom from the injurious pulping action which they allege is caused by its use, notwithstanding that the pressure continues only about twenty minutes for each batch of clothes. The claim of superior washing powers appears therefore to be problematical, the pressure being used only in boiling; and the author believes the truth is far more difficult to get at than would appear at first sight. Thousands of atmospheric washers are turning out clean work without difficulty.

The common adoption of steam pressure in washing machines from sanitary motives would appear to be due to the belief that machines which do not wash or boil under pressure are not sanitary. One of the advantages claimed for washing under steam pressure is that it destroys all infection. Authorities on this subject are unanimous in the conclusion that boiling clothes or other articles at atmospheric pressure is an efficient sterilizing process. In the treatment of wounds, where textile fabric chemically sterilized is not at hand, there need then be no fear in using what has come direct from the laundry, as it is to all intents completely free from infection. There does not seem to be any evidence of infection having been spread through laundries; and consequently, in spite of the slovenly way in which many laundries do their work, it would appear that they nevertheless happily afford a great protection from the spread of disease, and that where ordinary boiling is carried out there is complete protection. Flannels are never boiled, but are washed with potash soap, which is the best material to use, and is said to rank high as a disinfectant. The preference for atmospheric washing machines over those working under steam pressure depends upon the suitability of the machine to treat the clothes successfully with the least appreciable wear and tear, without involving too great an initial cost, and at low cost for labour.

A common form of washing machine used in Germany is shown in its general shape in Fig. 18, Plate 63. It is built on the same lines as ordinary rotary atmospheric machines, except that in nearly all instances the outside casing as well as the inside cage can be revolved, with the object of turning it round so that the doors shall come below when the clothes are ready for taking out. It is raised high enough on its bearings for a trolley to be run in beneath, into which the clothes are allowed to fall out. Although the saving in time does not appear to warrant the necessarily increased cost and other disadvantages of this plan, most of the German laundries are wedded to it.

Single machines which perform in themselves all the processes of chemically acting upon the dirt and clearing it away are open to the objection that, although the liquor is drained off between each operation of cleansing, a considerable amount is retained by the clothes, and helps to foul the next lot of liquor. An ingenious attempt has been made to construct a machine which shall perform all the operations in itself in a theoretically correct manner, and yet without any handling of the goods. For this purpose the outer casing of an ordinary machine is made to swivel, so that between each operation it can be turned with its axis vertical; the inner cage is then made to revolve rapidly, like a centrifugal machine, whereby the clothes are effectually cleared of the dirty water, none of which remains to contaminate the next lot of fresh liquor. It is not likely however that this machine will come much into use, owing to a variety of reasons which have nothing to do with the quality of its work.

In North Britain a machine is much used, shown in Fig. 20, Plate 63, having an outer casing of large diameter, which revolves in the opposite direction to the inner cage. The outer casing has inside projections, which carry the water up and discharge it continuously upon the brass bars that form the circumference of the inner cage, as shown one quarter full size in Fig. 21. The inner cage has large lifters, which raise the clothes for their fall. There is also an elaborate arrangement for discharging jets of steam upon the clothes, and the machine can be worked under steam pressure. It is obviously an expensive and complicated machine; and it has one fault common to all complicated machines, namely the difficulty of keeping it clean. Moreover it cannot wisely be made small enough to take only a small quantity of work, because its cost relatively to the output would then be prohibitive. Washing machines in general deal with such a large quantity of work at each charge, that only where large quantities of the same class of work need treating at one time can full charges be obtained; and then, in case of any error in the process of washing, the quantity of clothes treated is so great that it becomes a serious matter to correct the defect. For the finer classes of goods also it is questionable whether large machines do not have an injurious action.

Many other devices have been tried for washing clothes, and some are still in use; but while some of them may be of value for special requirements, such as hand power, the advantages of the few that have been described altogether outweigh those of all the rest.

Drying.—The first stage of drying is effected by a centrifugal extractor, of which any of the usual forms are suitable. The second or final stage of drying is performed by a drying room. The method of heating and arranging and working this room is important, and great improvements have lately been introduced. It is a subject too large to be treated here, inasmuch as no one method of heating the air for the drying room, or of causing it to act upon the clothes, has become at all general. The tendency is to adopt a plan of blowing air into the room, by using a blower to force it previously through an exhaust-steam heater. Some articles are not dried at all in a drying room, but are ironed at once, when taken direct from the centrifugal machine.

Ironing or Finishing Machines.—Ironing machines, in the variety of forms in which they are at present made, constitute what may be termed finishing machines. They all act mainly in the same way, although they differ greatly in design and capacity. In nearly all there is a hard polished surface of metal, which is heated by steam or gas or electricity; and a second hard surface of metal or wood, which is padded over with layers of felt covered with a wrapping of cotton sheeting. The padded surface holds the article which is being ironed, so that it can be made to rub against the polished heated surface, while allowing for irregularities of thickness in the article itself.

The first machine to be mentioned, and the only one of its kind, has no padded surface, but has two hard rollers, as shown in Fig. 22, Plate 64, of which the lower is a hollow cylinder, generally of brass, heated by steam inside; the upper roller is made of compressed layers of rag, cemented together under hydraulic pressure, and afterwards turned up true in a lathe. A roller of this substance, although expensive to make, acts with much less injurious effect on the linen than would two metal rollers, and yet has great hardness and durability. Linen, if constantly treated by the same machinery that is used in finishing it when new, would soon wear out; this rag-made calender however acts in a most innocent way. It is nevertheless suitable for only one class of article, namely table linen which requires starching; this it finishes in a superior style. The steam pressure in the heated brass roller should be not less than 50 lbs. per square inch, the corresponding temperature being 298° Fahr. The drying is slow, requiring the articles to pass through at least three times in order to finish them, when the speed is about 25 feet per minute. With these rollers it is difficult to finish the linen so that the edges are square and even.

The next division of ironing machines comprises those which finish the same class of goods as table linen, namely sheets, rubbers, smooth towels, and such other articles as are of uniform thickness. The usual width for these machines is 108 inches. The most common form is known by the name of its French inventor, Decoudin, and has been arranged in various ways, one of which is shown in Fig. 23, Plate 64. It consists of a large hollow cylinder of cast metal to hold steam, generally at a low pressure of only 5 lbs. per square inch, or 227° Fahr.; and of a hollow concave casting or chest, shaped to fit the cylinder, and having its surface polished and accurately finished where it touches the cylinder, and made to stand a steam pressure of at least 40 lbs. per square inch, or 287° Fahr. The cylinder is padded with several thicknesses of superior woollen felting, and revolves with a surface speed of at least 15 feet per minute. The chest is made to encircle the cylinder for as much as about three-eighths of its circumference. Sometimes the chest is above the cylinder, but far more often it forms a bed below. In some of these machines an arrangement is made to give the chest a transverse reciprocating motion if desired, parallel to the axis of the cylinder, so as to put a high finish on the goods in ironing them; but this has now been almost entirely given up. The action of drying is twofold. A wet article fed into the space between the cylinder and the bed becomes heated; and by the time it emerges from the other side most of its moisture has been driven into the padding of the cylinder, and a good deal of the remainder passes off in the form of steam while the article is cooling. A sheet which has come direct from the centrifugal drying machine is found to be well dried after passing through twice at a speed of about 15 feet per minute. During the time that the padding on the revolving cylinder is exposed to the air, the wet which it has absorbed is driven off in the form of vapour by the heat it has received from the steam chest or bed, aided by the heat of the steam inside the cylinder; and by the time it comes round again to the bed it should have become dry enough for acting on fresh wet linen. The cylinder, being uniform in shape and thickness, and not subject to extreme differences of heat and cold, never gives trouble by cracking; but the bed in many instances has become cracked so as to be rendered useless. Not only is the bed of irregular shape, but it has to stand a fairly high pressure for cast metal, namely at least 40 lbs. per square inch; and it is constantly having its upper surface alone cooled rapidly by the wet linen coming against it, thus causing great contraction and expansion. If the ends of the bed are left open in casting, and afterwards covered over with plates bolted on to make the whole steam-tight, there is much less liability of its cracking than if the ends are cast solid. The fault of the machine theoretically is that the steam evaporated cannot get away as fast as it is formed, but is bottled up until the wet part of the felting has passed completely clear of the bed.

To overcome this fault, machines have been made like those shown in Figs. 24 and 25, Plate 64, in which the central or main cylinder alone is heated, but is not padded; the rollers placed round it are all padded. The wet linen fed to the cylinder is carried round by its revolution, and pressed against its hot surface by the rollers, between which the steam can escape freely. All the rollers are pressed against the cylinder by spiral springs. Sometimes an extra roller is added on the delivery side, driven in the same direction as the cylinder so as to act as a doffer, for causing any article which sticks to the surface to be detached from it. In the machine shown in Fig. 25 a pair of rollers, of which the outer or polishing roller is heated and not padded, receive the linen after it has left the cylinder, and press it between them so as to give more finish to the upper side, which till then has come into contact with the padded rollers only. A speed of about 18 feet per minute is advised; the number of times it is necessary to pass the linen through varies greatly. The fault of this class of machine theoretically is that the linen is pressed into close contact with the metal surface of the cylinder only along a line, instead of for some width or length of circumference. The claim is not well founded that with the larger machines of this class sheets will be dry after passing through once; for, even with the machines in perfect order, the articles must be passed through at least twice.

Conduction and consequent drying are far more rapid where articles are brought into close contact with the drying cylinder by pressure, than where they touch it without pressure. One difficulty experienced in using these machines lies in getting all the rollers of exactly the same diameter; this arises partly from their surfaces becoming permanently compressed. If the first roller is too big, it passes the linen forwards too fast, and loosens it between the succeeding rollers, and thus prevents its proper contact with the cylinder. But if it is too small, it delivers the linen more slowly than the succeeding rollers take it, with the result of stretching and straining it. For this reason, although the machine may appear innocent of causing injury, it may really be doing constant and serious harm to the goods.

The machine shown in Fig. 26, Plate 64, has been designed for overcoming these difficulties, both theoretical and practical. It consists of four padded rollers, about 8 inches diameter, not heated, which are pressed by springs against four heated beds of cast metal; the latter are so arranged as to form one continuous bed, and each is hollowed out to fit the roller for some considerable distance. By this arrangement the linen is pressed against the heated metal surface for a considerable distance, while at the same time there are spaces at intervals for the steam to escape. The rollers, here working into surfaces accurately formed to the curve of their circumference, are far more easily kept true and of the same diameter. Steam up to 80 lbs. pressure or 324° Fahr. can be used, and the speed of ironing can be varied from 12 to 20 feet per minute. Sometimes an arrangement is added, as shown in Fig. 26, for finishing the upper surface of the linen, as in the preceding machine, Fig. 25; but here instead of two rollers there is one only, and a bed hollowed out to fit it. Linen taken direct from the centrifugal drying machine was intended to be dried by once passing through this machine; but although the drying power is great, the original intention has hardly been realised in actual working experience with the usual run of goods. The felting used for padding the rollers is not destroyed so quickly in these machines as the felt that covers the cylinder in the Decoudin machine, where it is rapidly burnt by the heat below, and requires frequent renewal. As the renewal involves a cost of some pounds, this is a point that requires consideration when choosing a machine.

A Decoudin ironer has been made, having the surface of the hollow cylinder perforated with many thousand holes, for the purpose of letting the steam generated pass off through them at once. This is a praiseworthy endeavour to overcome a real difficulty in a simple manner; but it has not made any headway, probably because the moisture does not pass through the padding, and the extra heating power of the steam in the cylinder is lost. One of the faults of most of the machines hitherto described is that the padding on the rollers or cylinders rapidly becomes compressed by use; and then the reduced diameter does not fit exactly into the bed hollowed out for the larger size when new.

Of ironing machines which handle the goods by the use of endless broad bands, the simplest is illustrated in Fig. 27, Plate 64. It consists of an endless band of heavy felt, guided by passing over rollers, which being made to revolve cause it to progress, and are so arranged as to make it press up against the polished convex under-surface of a hollow metal bed heated by steam inside. The details of this machine have been well worked out. The bed can be rotated on trunnions, so that the polished surface can be carried away from the damp band when not in use, and also for cleaning. The band is held up against the heated surface at two places with considerable pressure, by means of two loose rollers AA, which not being driven independently have no action either to stretch or to loosen the linen passing over them. The lower roller B can be depressed or raised so as to give the right degree of tension to the band; and to overcome the difficulty of the band contracting and narrowing in width under certain conditions, this lower roller is made with one half having a shallow right-hand thread upon its surface and the other half a left-hand thread, of such coarse pitch that the effect is to stretch the band wider. The machine is not made to revolve rapidly, because if it were the band would probably not get dry during the time that it is not being held against the hot bed. It is run at about 12 feet per minute, and at this speed the goods are found to be properly dried by once passing through. The band is said to last for twelve months, but is expensive to renew, costing about £8. This machine is said to consume little steam, although it is not apparent why this should be so.

The machine illustrated in Fig. 28, Plate 64, consists of four steam-chests, or a smaller number, connected together by an end chest; and of an endless band of cotton duck, which is so guided by rollers as to pass over all the steam-chest surfaces and to be pressed heavily against the recesses of the end chest by means of padded rollers. A lower roller B is used for regulating the band to run true or straight, without working either to right or to left. Another roller A is arranged for keeping the band properly stretched. Although relatively to the size of the machine a large extent of heating surface is here presented for drying the linen, yet over most of the surface there is but little pressure of the linen against it.

The machine shown in Fig. 29, Plate 65, is a curious combination of those shown in Figs. 27 and 24 or 25. The cylinder is of considerable size, namely 48 inches diameter, and is heated by steam. An endless band of light canvas carries the linen against the under side of the cylinder, after it has been acted on by the top pressure-rollers; and in combination with another endless band or apron carries it back again, so as to deliver it on the opposite side to that at which it was fed in. The machine was designed with a view to getting through a large quantity of work. It is of course expensive, and would appear to possess most of the faults of the two machines of which it is a combination.

The machine illustrated in Fig. 30, Plate 65, is a combination of a Decoudin with that shown in Fig. 27. It has two beds and two felted rollers, so arranged as to act on both sides of the linen, having steam in the beds only and not in the rollers. After the linen has thus been doubly acted on, it is carried by an endless band of canvas around and against nearly the whole circumference of the large heated cylinder, which does not revolve; and is then carried some distance beyond it, so as to give time for the steam to clear away before it is delivered to the receiver. This machine appears to have many recommendations, and at a speed of 30 feet per minute will dry ordinary sheets with once passing through. It is the simplest machine of the kind. The difficulty the steam has in getting away is still a fault in these later machines.

An arrangement has been tried for blowing away the steam from the clothes directly they have passed from the heating surfaces; but its efficiency is doubtful. Fig. 31, Plate 65, shows an ironing machine which ought to dry linen after once passing through. It is really two Decoudin ironers combined into one, and thus does away with the handling of the goods between each feed. The special point about it is the endless band on the first roller, for preventing the linen from clinging to the roller. The rollers are both padded, and hence the band should allow the moisture to pass through it into the padding of the first roller, unless it can absorb largely itself. One fault is that the moisture, which in its heated state would evaporate, has not time to do so while the linen is passing between the rollers; but this is overcome at least partially by the surface between the two rollers being heated. The speed of the machine is about 17 feet per minute. It appears to be a genuine attempt to overcome the loss of time and labour in passing linen twice through a Decoudin ironer, and has the merit of presenting a good arrangement for feeding the linen in.

In comparing the merits of these various machines, it may be noted that, provided the metal surfaces are well polished, there is no need to fear the linen sustaining wear when drawn over them, even when under considerable pressure such as is used in the Decoudin ironer. So far as economy is concerned, it must be remembered that the same number of attendants are required, whether the machine does much or little work; and also that there is a practical limit to the speed at which a machine can run, because if too quick the articles cannot be fed in evenly. The machine is required to deliver the articles free from creases, of correct and even shape, and with a good finish on the surface. This last requirement is seldom fulfilled, especially in the larger machines, and sometimes no surface is put on either side. The greater the heat, the better is the finish of the surface. So far as speed of working is concerned, any machine which runs at 25 feet per minute, and dries the linen properly by once passing through, is not far wrong. The value of the heating surface is governed by the amount of pressure with which the article is held against it; by the temperature to which it is heated, that is, by the pressure of steam it will stand; and by the ease with which the water can be got away from it in the form of steam. A further point is the ease with which goods can be fed in correctly. One difficulty, not yet satisfactorily overcome in most machines, is in finishing starched goods, owing to their adhering to the padded surfaces. The calender however is satisfactory in this respect. On the whole the machine shown in Fig. 30, Plate 65, —namely a double Decoudin ironer combined with a stationary drying cylinder—appears to present many good qualities and to be fairly free from faults, where finish is not required.

Collar and Cuff Ironer.—In Fig. 32, Plate 65, is shown the principle of working of a collar and cuff machine, which in a general way appears to be a nearly perfect machine of its kind. The main parts are a horizontal rigid bed, padded on its top surface, and when working supported on a roller beneath, by which it is made to slide forwards and backwards; and a smaller hollow upper roller, made of cast metal, and heated by gas jets inside, against which, by raising the lower roller by a treadle, the upper padded surface of the bed is pressed. The goods laid upon the padded surface of the bed are dried by the heat of the hot roller above. It is important for the top roller to be made of exceedingly fine grained metal, and to be turned perfectly true and highly polished. The roller is driven at a greater surface speed than that at which the bed travels, thereby causing a skid upon the linen that is being ironed; the relative speed varies in different machines, but nearly 2 to 1 is often used. The ease with which the machine is handled, and the quantity of work it gets through, are so great that it is now in extensive use. One difficulty connected with it is in the bearings of the heated roller; owing to the pressure with which the bed is forced up against it, and to the great heat at which it is worked, the bearings are troublesome to lubricate and liable to grind.

Linen and Flannel Ironer.—An ironer for body linen, much used in America for general work and in England for flannels, consists of two long rollers of equal size, each about 6 inches diameter, which are made to project horizontally up to 3 feet overhang from the frame of the machine, and are geared together to revolve at equal speed. The top roller is polished cast-iron, turned true and heated inside by gas jets; the lower roller is solid and padded, and can be raised to press up against the upper, or lowered away from it, by means of a treadle; the act of lowering puts it out of gear. In order to ensure all the parts of the article being ironed uniformly, it is moved about continuously by hand while still between the rollers, but while they are not pressed together; and inasmuch as it is always on the bottom roller, the loss of time is small for shifting it, either to iron any portion a second or third time, or to bring a fresh part to be ironed. The rollers have a surface speed of about 25 feet per minute.

In such a wide subject as that of this paper, the author has endeavoured as far as possible to deal only with the principles of the machines described, and to avoid unnecessary details of laundry work in general. The numberless small machines which find favour in America for ironing special parts of garments have purposely been passed over; as have also the ingenious machines for starching, which appear to be slowly forcing their way into use in this country.

Discussion.

Mr. H. S. WOOD, of Messrs. Thomas Bradford and Co., asked for some explanation with regard to the washing machine shown in Figs. 4 and 5, Plate 61, as to how the water was raised from the bottom of the casing to the level of the axle of the revolving cage. The engine power ordinarily sufficient had been mentioned in the paper (page 269) as about that of a 9-inch cylinder engine running at 60 revolutions a minute, whereas it varied considerably according to the size of laundry; many laundries used engines of as much as 20 or 30 horse-power. Besides those described in the paper, there were several other kinds both of washing and of ironing machines, which were manufactured by the firm he was connected with. Instead of 2½ to 3 hours being required for washing ordinarily soiled linen in the rotary machines (page 271), his own experience was that 50 to 60 minutes was all that was needed, including the combined operations of washing, boiling, rinsing, and blueing.

Mr. Druitt Halpin had some years ago put up a large laundry, in which Lord Kelvin's screw-down cocks were adopted. They were then new, and they did not answer. Since that date, instead of metal a new vulcanite substance had been employed for the valves, which he had had in use for some years with complete satisfaction, both for hot and for cold water, and without the least leaking; the valves were absolutely tight. The material of the valve was some form of vulcanised rubber, but he did not know exactly what was its composition.

The President asked whether that was the same valve as Lord Kelvin's.

Mr. Halpin replied that it was, with the new substance which the manufacturers had put in.

The use of a fan properly arranged for carrying off the steam, which was referred to in page 271, was certainly most essential, and he considered was easily arranged. The same was the case in regard to the adoption of blowers for forcing air into the drying room (page 280). In another laundry which he had put up, where the artificial drying was effected by a large range of pipes, the air was drawn over these at the rate of some 12,000 cubic feet a minute by means of an exhaust fan, instead of by a blower, and could be heated by them up to 150° Fahr. That was of course an unsuitable temperature; it was the limit available, if desired. The result was that in the

(Mr. Druitt Halpin.)

laundry, which was a large one, it was impossible to tell by the atmosphere that it was a laundry at all; it was like an ordinary room. Everything was drawn inwards towards the fan; and considering that 12,000 cubic feet of air a minute were drawn in, there was evidently little chance of soap-suds or any other cause of smell or any dampness being perceptible in the atmosphere of the place. As a means of saving labour the goods went in at one end of the large drying closet, and came out at the other, so that there was no passing backwards and forwards. Working in that way, there was a minimum of labour; and considerable quantities of the heaviest and therefore the dampest goods were dealt with and dried in about seven minutes in the closet, through which passed the whole quantity of air drawn into the drying room by the fan, namely 12,000 cubic feet a minute.

For water softening it was said in page 269 that whatever apparatus was used must be of the utmost simplicity. The great advantage of having water-softening apparatus in laundries was well known, although separate water-softeners were not always put up. Generally trust was placed in softening by the addition of chemicals to the water, which afterwards came into direct contact with the clothes; and some persons had an idea that these chemicals did not do the clothes much good. It struck him that the most natural way to soften water was not to do it with chemicals at all, but by applying heat and working on the plan of thermal storage. Lately he had obtained some facts with regard to the New River water, which was fairly bad, having 14·7 degrees of hardness* on Dr. Clark's scale; when dealt with by one of the best form of softeners he knew of, namely by one of the modifications of the apparatus for carrying out Dr. Clark's process, the water was brought down to 6 degrees of hardness. On heating it by thermal storage, without any chemicals or any other treatment, it was brought down to 6·9 degrees; that was in a test made in the north of London; and the hardness had since been brought considerably lower by the same plan. Even the harder chalk water of the Kent Water Works, which was also a worse water on account of its containing one of the most objectionable forms of lime, namely the sulphate, had been brought down from 19·2 to 5·6 degrees of hardness, absolutely without the use of any chemicals, and merely by the use of heat. Formerly it had been thought that the deposit in boilers and in other similar vessels was caused simply by the water evaporating away; but the action was now known to be due to the fact that the mere elevation of temperature brought the deposit down; and the deposit would come down and stay down, if it were only treated in that way.

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* Each degree of hardness corresponds with one grain of carbonate of lime dissolved in one gallon of water.

The President asked whether the temperature to which the water was heated was short of the boiling point.

Mr. Halpin replied that it was above the boiling point at atmospheric pressure. In order to bring down the last of the sulphate, the temperature had to go up to 307° Fahr. This simply meant about 75 lbs. absolute pressure per square inch; and he failed to see any difficulty in it. In some of the machines described in the paper pressures up to 60 and even 80 lbs. were stated to be used; and the corresponding temperature was therefore high enough to bring down the whole of the deposit without any chemicals at all.

Mr. E. Fuhrmann Clarke said that in designing the arrangement of a laundry his own experience had been that one of the most necessary points to consider was that all departments should be accurately balanced as regarded their working capacity; it was easy to get one department out of balance with the others. The one which had the least capacity regulated the total amount of work that could be done throughout the whole establishment. At the outset of the paper the remarks on the arrangement of the laundry seemed to him to be applicable practically to what might be called domestic laundries, rather than to what might be designated institution laundries, which latter had to be designed in a decidedly different way. His experience went to show that, if the washing and drying were treated together as one department, the machine ironing as a second, and the hand ironing as a third, they severally occupied

(Mr. E. Fuhrmann Clarke.)

about one-third of the total area required for the actual work of the laundry, irrespective of the sorting and packing and other minor requirements.

The power necessary to be provided in designing a laundry was an important point to settle satisfactorily, on which he should be glad to learn more fully the author's experience. The information given in page 269, that a 9-inch cylinder engine running at 60 revolutions a minute was sufficient, seemed hardly to coincide with modern practice, and the number of revolutions seemed more suited to an engine indicating 250 horse-power, which would be much more than sufficient for the largest laundries. In a general way the capacity of a laundry was best expressed by the value of work done per week, which of course varied with the prices charged. In his experience he had found that, if from 1¼ to 1½ indicated horse-power was allowed for every £10 capacity of work per week, the engine power would be about suitable for the size of the laundry.

The heating of the water or other washing liquors was not always done by turning live steam into them direct (page 269). Though this method was extensively adopted, he had himself used surface heating as well.

The use of exhaust-steam injection for feeding the boiler (page 269) he thought it was advisable to avoid, in order to prevent the danger of oil getting into the washing machines. The exhaust steam was of value for heating either the building or the water. Excellent results had followed in his own experience from sending the steam from a compound engine exhausting at a low pressure through a heater of much larger size than would be commonly adopted for feed-water with the engine employed; flow and return pipes were connected with a receiver above, and circulation took place in a similar way to that in an ordinary domestic hot-water arrangement. By this means he had been able to keep a constant supply of reasonably hot water for use throughout the laundry. The feed-water heater used was one by Royle of Manchester, made with Row tubes; these were solid-drawn copper tubes, squeezed or flattened transversely by successive indentations alternately at right angles to each other, so as to break up the current of steam and prevent any part of it from passing through the tubes without coming into surface contact, and thereby to render their heating surface more effective. The heater had given excellent results, and had been at work now for nearly three years without any trouble whatever; it kept the laundry continually and fully supplied with water at a reasonable temperature, and caused no back-pressure whatever in the engine. [See page 306.]

For the water pipes supplying the washing machines (page 270) he had certainly not found it necessary to use copper piping. In fitting up a large establishment he thought it would be almost prohibitive in cost to use copper piping with brazed unions; and he should be glad to hear of the experience of others in this matter, whether they found any great difficulties. In the use of ordinary galvanized-iron piping throughout a laundry he had never found any special difficulty.

The President asked how long the galvanized-iron piping had been in use; and whether any iron mould had been found to occur from its adoption?

Mr. Clarke replied that he had had it in use for about five years, and had not found any iron mould from it. A certain amount of iron mould had occurred where pieces of piping not galvanized had been used; but since these had been replaced by galvanized piping he had had no trouble whatever from iron mould. As to galvanized iron being specially affected when it came into contact with wood (page 273), he had not found that to be the case when the galvanizing was properly done; but of course if the iron was not properly galvanized it would become affected by any moisture.

The President asked what kind of joints were used for the galvanized-iron piping; and whether they affected the galvanizing in any way, by cracking or abrading it.

Mr. Clarke replied that they were ordinary screw joints, and he had had no trouble with them at all.

(Mr. E. Fuhrmann Clarke.)

The method of washing by letting beaters act upon the fabric, as in the dolly machine (page 272), he had been told was employed in Nottingham for washing the whole of the lace curtains which were made there; and from the author's former experience in that district he might be able to give some special information about the working of machines of that kind. In the paper they were spoken of as suitable only for washing tent cloths, which he supposed were reckoned as rough material.

For the doors of washing machines, particularly of the kind shown in Figs. 4 and 5, Plate 61, he had specially adopted a fastening including four bolts acting simultaneously, which closed the door in a perfectly effectual manner; and he found no difficulty with this plan. It was quite true that the doors of washing machines were a prolific source of trouble (page 273); but the only thing required was to fasten them in a great number of places, and not leave too much spring in them.

It seemed to be implied in page 272 of the paper that the washing machines were kept working at the boiling point. His own experience however had been that it was a great mistake to work a rotary washing machine at boiling point, and that while the boiling took place the machine should be allowed to stand still; otherwise there was a considerable danger of injury to the fabric, if the boiling and the rotation of the machine were going on at the same time. No doubt one great fault in the construction of most of the rotary washing machines was the exposure of sharp edges of metal on the internal surface of the revolving cage; and this was a matter that had not been considered important until recently. The lifter C in Figs. 9 and 12, Plate 62, was one that he had in use in some machines now working most satisfactorily; the mode of attachment to the cage was such as to prevent any sharp edge of metal from coming in contact with the clothes. The plan of lifting the clothes and letting them fall into the water he believed was supposed to constitute the washing action; but if a machine of the size shown in Figs. 4 and 5, Plate 61, was filled to the extent suggested in the paper (page 275), he thought there would not be much room for the clothes to fall, however high they were lifted. As to the exact process of washing in these rotary machines, he thought engineers were still much in the dark. No doubt the clothes were lifted and fell; but there was little or no surface of water for them to fall on. The surface they actually fell on he believed was the clothes themselves that were in the process of rising again. Most of the washing he thought was done by the friction of the clothes one against another; and as long as that friction was not too severe, there was no likelihood of damage in using the machines.

In the matter of drying he had found that the plan of drying by drawing air through a heater, and then blowing it through the clothes (page 280), was satisfactory; but a good many other methods were no doubt in use. The difficulty was really to get a sufficient amount of work dried within a reasonable space in comparison with the size of the rest of the laundry.

Mr. W. Worby Beaumont said the paper showed how large an industry had grown up for this particular class of work in a comparatively small number of years. For drying, the plan mentioned in the paper (page 280) and referred to by Mr. Clarke (page 295) had been found quite satisfactory and had worked well, in a rather large establishment in which he had recently put up some laundry machinery. The advantage was that the engine which drove the shafting for working the machines might exhaust into the heater, and at the same time drive the fan which was sending the heated air through the drying room.

Of the different ironing machines he had not had any experience; but he thought many like himself had had some experience of the results of their employment, and had found in the last few years that they needed new collars and shirts much more often than they used to do when these articles were washed and ironed by hand. Although so much had been done already, he thought there was certainly great room for improvement in ironing machines, if not in anything else; a machine was wanted that would imitate better the handwork of those whom he had recently heard spoken of by a laundry attendant as the ladies who did the ironing. If some judgment could be associated with the working of the machines,

(Mr. W. Worby Beaumont.)

instead of a hard and fast pressure such as was obtained even with a roller running on a padded surface like that described (page 287) for the collar ironer, Fig. 32, Plate 65, a great improvement might be brought about.

For softening water he thought there was no doubt that Mr. Halpin's thermal storage system (page 290) was the best, wherever it could be applied. The temperature that was necessary involved what would nowadays be considered only a comparatively low pressure, about 75 lbs. total pressure of steam, equivalent to about 310° Fahr.; and it avoided all the risk that attended the use of different chemicals. In the use of a Royle heater (page 292) he should like to know what water it was that was heated in the heater which had remained in good and effective operation for about three years. The advantage of the thermal storage plan was that it supplied always such an ample quantity, not only of the softened water, but of the heated water.

Why it was that the piping should seem to be such a difficulty (page 270), he could not quite understand. Surely engineers who were accustomed to make steam joints in piping for pressures up to 200 lbs. per square inch ought to be able to make satisfactory joints, and to arrange the piping in such a way that neither by vibration nor by contraction or expansion nor by the pressure should any trouble be occasioned.

There were some washing machines which were so made that the doors need not necessarily fit tight. The cage revolved in a large open vessel, by which it was only partly surrounded; and the clothes put into the cage were kept in it by a door which was of open work only, and the fastenings to keep the door in its place were quite simple, and as far as he knew gave no trouble whatever.

In a laundry of some considerable size, he should like to hear how far the provision of 1¼ to 1½ indicated horse-power for every £10 worth of washing done per week (page 292) was the experience of others. The different prices for different sorts of work carried out in different laundries he supposed would cause the value of the same quantity of work to fluctuate above or below £10.

Mr. GEORGE H. HUGHES considered the speed of 60 revolutions a minute with a 9-inch cylinder engine (page 269) was too slow, and that the normal speed should be about 180. The principal point determining the power of the engine was the size of the centrifugal drying machine. Whether there were one large or two small centrifugal machines, an engine was required with sufficient power for starting them from rest and getting them up to speed. None of the other machines took so much power. The pipes to be used would depend on the quality of the water. With the London water, which was fairly hard, there was not much trouble in using galvanized pipes; but in some country places there might be difficulty in using them, owing to the water acting upon them, especially in the neighbourhood of Tunbridge Wells and other places, where the water was rather difficult to deal with and required special pipes to be used. Good pipes were now made with white porcelain enamel on the inside; and there were also glass-lined pipes. Special attention was required in reference to the joints. In examining the water pipes in a laundry, he had found that the inside of a galvanized socket had rusted quickly, and the water had attacked the edge of the pipe where it had been cut into by the tube-cutter; this had caused corroding action at the joint, and might cause iron mould on the clothes after the pipe had been in use for a year or two.

The PRESIDENT asked whether this had been found to occur more with lime water or with soft water.

Mr. HUGHES replied that it occurred both with soft and with hard water. For softening the water, his own experience was that nothing was better than the ordinary Clark process, provided there was sufficient room for carrying it out in the laundry. There were other good plans of softening water on the continuous method, which answered well. To heat the water in order to soften it he thought must be expensive compared with softening it by Dr. Clark's process, which cost probably about one penny per thousand gallons, including three farthings for labour, maintenance of plant and tanks, and interest on capital, and one farthing for lime or other chemicals; the

(Mr. George H. Hughes.)

cost he imagined must be considerably more for heating the water to 300° Fahr. The Kent Water Works water was softened at the Herbert Hospital, Shooters Hill, by Dr. Clark's process, which was found to be highly satisfactory and had been used there for some years. The hardness was reduced from about 18° or 20° down to about 4° or 5°. About the mode of drying (page 279–80) he should like to have had more particulars. In one steam laundry with which he had been concerned, the steam coils used for heating the drying closets had been a source of endless trouble. The coils were heated with low-pressure steam, and the flanged joints on the bridge pipes connecting the ends were continually leaking. The ends of the pipes forming each tier, consisting of about ten pipes, were connected together by one large casting; and when the steam was turned on, the unequal expansion of the pipes in each tier caused the joints to blow. This difficulty was remedied by substituting bends for the large casting, and connecting the series of pipes in gridiron fashion, so that the end castings or bends were free to move; and there had been no further trouble. As to the ventilation of the drying chamber, he thought in a properly constructed chamber a natural draught would be quite sufficient, without any extraordinary means of ventilation either by driving the air in by a blower or exhausting it by a fan.

Mr. Tebbutt said the paper had been difficult to write because of the modern nature of the industry of which it treated, and because he had been anxious to deal only with those points which were interesting to engineers, and also because many engineers perhaps had as yet had little experience of what a modern laundry was like. Therefore it had seemed desirable to introduce many remarks which were simple in themselves, and must appear elementary to laundry engineers and to others who were technically acquainted with the business. This was really the explanation of what he had written, for instance, about the arrangement of the laundry itself, about which the remarks made by Mr. Clarke (page 291) were to some extent correct. Instead of two long bays running side by side, a better arrangement for a laundry would perhaps be three long bays running side by side; and the only object of the description offered at the outset of the paper had been to explain roughly what a modern laundry consisted of, so that any one unacquainted with this particular kind of work might have some conception of its general features. It was further difficult, he thought, to arrive at anything like the actual facts of much of this industry from the experience which had been gained thus far. It might perhaps seem to many persons who were unacquainted with laundry work that it would be easy enough to find out the truth on many matters connected with such processes as those of washing clothes and of handling them in drying, because this industry was already a large one, much larger indeed than might be supposed: indeed every industry was always large which touched all classes of people. The handling therefore of such an amazing quantity of clothes week by week might seem to indicate that on most points some definite conclusions and some general practice ought by this time to have been arrived at. On many points however he had found that there was as yet much diversity. In so modern an industry as the application of steam power to laundry work, general practice was being arrived at gradually, and indeed methods differed as yet in nearly every department. Thus of the washing machines he had been able to describe only a few, because their name was legion. Many of them had only budded for a short time, and then disappeared again; and he had therefore tried to describe those which he thought were of most interest, or in common use.

The question of the size and speed of the engine he thought was of rather secondary importance. In page 269 the number of revolutions per minute was given in error as 60, and should have been 120. The easiest and simplest mode of settling the power practically would be to indicate the engine for the power required by the various machines; the power required for driving them when all were running would thus be arrived at closely enough. The mode in which the power had been stated by Mr. Clarke (page 292), namely the horse-power required for getting through a given quantity or value of work per week, was decidedly preferable to prescribing any particular size and speed of engine as likely to be

(Mr. Tebbutt.)

suitable for all requirements; and the amount of power mentioned seemed to him to be correct, and to agree with that given in the paper for the size of laundry which he had particularly had in view. The hydro extractors or centrifugal machines, which were universally used now, did to a certain extent determine the power of the engine (page 297). For this reason some engineers preferred to have a hydro centrifugal extractor driven by its own engine; but though this was often done, he thought it was a mistake from the laundry point of view. As a matter of fact the power required to start a centrifugal machine and get it up to speed was considerable; he had been astonished to find that it took from 4 to 6 horse-power to start a small centrifugal extractor of only 26 inches diameter, and bring it up to its proper speed of say 1,000 revolutions a minute. With larger hydro extractors therefore it might well be that the centrifugal machine to a large extent determined the size of the engine. Altogether the power required for driving a laundry was so small and unimportant that he had not regarded it as a matter of any great interest to engineers. The size of engine given was meant to drive the more common size of steam laundry represented by say £5,000 capital. In this, as in various other particulars, many of the statements made in the paper had been couched in general terms, in view of the many differences of opinion likely to be met with; the main object had been to put on record what was the general state at present of an industry developing so rapidly as the laundry industry. The information now recorded might perhaps afford a basis for the future development of laundry machinery, and might possibly help to a firmer grasp of the general principles which governed the design and arrangement of laundry machinery.

To the charge of destruction to the clothes (page 295) he thought the better class of steam laundries need not plead guilty. It was the requirements of the customers themselves which in his opinion largely determined the time the clothes would last. The wearers expected nowadays so much more than they used to expect, and at the same time they forgot that they were now getting much more than they got in the past. Looking back twenty years to the manner in which the linen had then been got up, particularly glazed work such as collars and fronts, he thought what had formerly been worn would not be accepted now. If certain results were expected in the appearance of such articles, they had to be paid for in the shape of extra injury or wear of the fabric. The material itself was often inferior, not being intended to last. Starch moreover was powerfully rotting in its action; and his impression was that when it was heated greatly and under a fair amount of pressure, as in these ironing machines, its action was still more injurious to the linen. How far the linen was injured by the skidding action which was employed in order to produce a gloss or finish on its surface, he did not know; he did not himself suspect that this had particularly to do with the greater wear, though he never could quite find out why collars, for instance, appeared to become rotten or destroyed so quickly. The reason he thought was to be found in a combination of causes, one of which certainly was that at the present day the wearers were so much more luxurious that they had their collars washed oftener than formerly, with the natural consequence that the fabric was worn out so much sooner.

Of softening water by heat, as in Mr. Halpin's plan of thermal storage (page 290), he had had no experience at all; and he should like to know something about the cost, the quantity of water treated, and how far the plan was suitable for laundry work. In a laundry it must be borne in mind that those who managed it were not skilled persons, and had not any skilled labour under them, or at least ought not to have any. If the price of skilled labour had to be paid, it would run away with so much more money, which would be better employed in other ways. There was not any serious difficulty he thought in connection with the simpler modes of softening water, such as running the water into large open tanks, and there mixing it with a certain amount of softening solution, so long as this process was done with ordinary care and regularity. Those who had properly investigated the matter had found that the softening could thus be carried out generally with satisfactory results; and with proper apparatus it could be accomplished easily. The destructive action of water chemically softened was not really a source of any great trouble

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in a laundry; he was himself softening water of 25° of hardness down to 5° without any evil effects. The amount of saving in materials by any highly scientific method of softening, whereby water could be brought down to 4° of hardness instead of 7° or 8°, was not of serious consequence. It might be roughly stated that in a general way 4 or 5 per cent. of the whole expenditure of a laundry was all that should be spent upon the washing materials, including starching. Therefore the saving effected by the most complete and scientific plan of softening water would not be worth having, if it involved an elaborate apparatus.

It was because nearly all laundries failed so much in obtaining proper piping that this point had been dealt with in the paper. Unnecessary complication of piping was a common fault in most laundries, and greater care he considered should be exercised in the arrangement of the pipes from the beginning. They were often got in anyhow, one after another, without any care being taken in arranging them beforehand. Moreover piping was almost invariably put in too small. The water pipes should be much larger than they usually were, for he had found that the time lost in running water through them was too great. Copper he considered was the best material for water pipes, better than galvanized iron, because such a large bore was required that galvanized-iron piping if large enough would be too heavy and not nearly as satisfactory. The joints of galvanized piping had certainly been found to deteriorate rapidly, unless they were constantly protected by paint or otherwise; for this purpose he had tried to use various materials, such as were used for protecting ships from sea water, but the attempts had proved unsatisfactory. Copper piping also he believed was much more easily cleaned out; and it was much more easily handled, because it was so light. It was only for water that he suggested its use, and not for steam. The price of thin copper piping was not at all prohibitive of its use. Such a simple matter as filing out the burrs left inside the ends of the pipes after they had been cut he might be forgiven for bringing forward, because, while its importance was well enough known, it was one of those many small details which were constantly being neglected in this class of work.

The raising of the circulating water up to the level of the axle of the revolving cage (page 288) in the washer shown in Figs. 4 and 5, Plate 61, was effected in a simple way. The disc forming each end of the revolving cage was like a wheel made with twelve radial ribs or spokes of T section, the ends of which were closed in by a flange or ring round the circumference of the disc. Each spoke thus formed a radial trough, into which the water lying in the bottom of the outer casing entered through a hole in the disc, and being carried up by the rotation of the disc was discharged into the cage at the level of the axle through a hole in the inner plate lining the disc. By means of the circulating action thus obtained, the water was delivered into the revolving cage at the most suitable place, instead of being put into it at the bottom or elsewhere, when probably it would hardly be got into the cage in sufficient quantity.

While it might apparently be simple enough under ordinary conditions to keep tight the valves of the piping, he had seldom been into establishments using steam or water without finding some joint or valve leaking, even in businesses where engineers were working all over the premises. In a laundry, where the piping was probably looked after by the engine-man driving the engine and by the stoker tending the boiler, and where there was so large a quantity of pipes, it would be found that there were a great many more leaks taking place. There were girls constantly screwing the valves in and out as hard as they could screw them; and it was difficult to find suitable valves to stand that forced treatment long. There were now many methods of constructing valves with removable seats made of special materials, so that they could be renewed without having the valves ground in afresh. These however had not been used sufficiently long he thought to prove whether they were good or bad. One or two which he had tried he had not found good. The last he had tried was of india-rubber, and was the best he had met with; and he thought the difficulties would ultimately be overcome. Certainly these matters, although they might appear small, were such as might interrupt the steady and continuous working of a laundry, which was really a manufactory; and general experience had shown that in starting a manufactory of any description a

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leading object should be to obtain as continuous and smooth running as possible. A laundry should continue to work hour after hour without any stoppage for repairs; and he believed, if proper care were taken in all these small details at the beginning, such stoppages would not occur.

The method of washing by dollies or beaters (page 294) he thought was generally regarded as not advisable for light fabrics; and he did not know any modern laundries where it was in use. While engaged formerly in the manufacture of lace and of lace curtains in Nottingham, he had not inspected the washing machines in which those articles were being washed, and was therefore unable to give any technical information as to how they were treated.

No doubt it was the friction of the clothes against one another (page 295) which had the greatest effect in enabling the washing to be effected, because the large quantity put into the revolving cage caused them to gather into a large mass, and the washing solution in the cage could not act directly on all of them; so that, unless they fell over during the revolutions, there would be no friction of one against another. It was the fall he believed which produced the friction; and if a machine was worked with too small a quantity of water, as was often done, it would have an injurious effect upon the clothes. The clothes should fall he considered upon something which would give, and the machine should be worked with a fair quantity of water in it. That the clothes really were lifted and did fall over (page 294) when a cage was as full as suggested in page 275 he had no doubt whatever, because their fall could be heard; it could not be seen, and it was necessary to listen attentively in order to hear it if the machine was running at a reasonable speed. When lifters were employed, which he had no doubt was by far the best way of making a washing machine, there was necessarily a lifting even when revolving slowly, and consequently a fall, and it was the latter which produced the washing action.

The time required for washing (page 289) varied greatly with the class of clothes. Some of the clothes were so clean that they hardly needed washing; and others were so dirty that they could hardly be got clean. For the latter the washing action was largely a chemical process, and one person might understand better than another how to treat them chemically. The chemical process he considered was much more important than the mechanical; washing might rather be regarded indeed as a combination of the two, the object of the washing machine being to enable the chemical action to take place under the most favourable conditions. The dropping action he thought was the only one which thoroughly forced the liquor right into the middle of the mass of clothes in the cage.

It was not intended to be implied in the paper (page 272) that the clothes were heated to boiling point while washing (page 294). But while the boiling—not washing—was being done, he considered the cage should revolve, in order to get all the clothes well acted on. Upon the question of washing under steam pressure or at atmospheric pressure he should like to have heard some remarks, as this seemed to him to be a highly important point. If there was really any advantage from a sanitary point of view, which he understood was generally held to be the reason for the more expensive and more troublesome method of washing under steam pressure, this plan ought of course to be adopted. But all the authorities he had consulted on the subject of disinfection, English and German writers alike, were unanimous in stating that anything which was subjected to boiling at atmospheric pressure, that is, at a temperature not exceeding 212° Fahr., would be perfectly disinfected thereby. Instruments about to be used in surgical operations he was told were dipped in boiling water beforehand, and were then considered quite safe from infection; and for the dressing of wounds, if properly prepared bandages were not at hand, it was considered practically safe to use linen or other articles brought direct from a laundry, on the assumption that they had undergone a proper boil at atmospheric pressure.

The President had great pleasure in proposing a vote of thanks to Mr. Tebbutt for his interesting paper on steam-laundry machinery. It was an industry that was largely growing, and too much could not be known about the best methods in which the work could be done. There were a number of laundries on the Midland Railway, and his

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own experience of them was that iron mould could not be got rid of without putting in copper pipes. Another thing, highly desirable to be aimed at, was that when the clothes came home there should not be great holes and slits in them; these probably arose a good deal from the carelessness of the persons who attended to the machines. Apparatus for softening water was in use on the Midland Railway; at Derby it was found that the cost (page 297) of softening the river Derwent water was about one penny per thousand gallons, to reduce the hardness of the water from about 15° down to 4° or 5° on Dr. Clark's scale; this included chemicals, labour, and interest on capital outlay.

Mr. John I. Thornycroft, Member of Council, had much pleasure in seconding the vote of thanks. The subject of the paper was one of great interest, and there seemed to be a difference of opinion as to what the process of washing really was: whether it depended upon the friction of the clothes against one another, or upon some other action. It appeared to him that the chemical agency was really the true cause. If the liquor could be made to pass through the fabric with only the fluid friction, he believed that by simply passing through, with or without air, it would bring the dirt away. If so, he thought this was a highly desirable aim to be realised.

The vote of thanks was passed unanimously.

Mr. John M. C. Paton wrote that, so far from any fabric of less strength than tent cloths being always injured by washing machines using beaters (page 272), the whole of the lace made by machinery in Nottingham, including the most delicate lace curtains, was washed in dolly machines having falling beaters or vertical stampers much heavier than any that had ever been used for regular washing in laundries.

Mr. E. Fuhrmann Clarke wrote, in reply to Mr. Beaumont's enquiry (page 296), that the water heated in the Royle heater which had been in use for three years was pumped from a well, and had a total hardness of 6 degrees on Dr. Clark's scale ; 5½ degrees were permanent hardness, and ½ degree temporary.

Mr. TEBBUTT wrote that for softening large quantities of water the cost mentioned by the President (page 306) was confirmed by experience elsewhere. New wool was washed on the method recommended by Mr. Thornycroft (page 306).

MEMOIRS.

Thomas Edwin Bickle was born at Hayle, Cornwall, on 5th December 1857, and after being educated there at a private school served his apprenticeship in the engineering works of Messrs. Harvey and Co., at the same time studying in the science classes held under the auspices of the Mining Association of Cornwall, and obtaining numerous prizes. Subsequently he attended several courses of lectures in engineering subjects at South Kensington, and obtained the foremost position in steam and applied mechanics. After considerable experience in erecting for Messrs. Harvey mining machinery in Cornwall and pumping machinery in London, he founded in 1888 the engineering works of Messrs. Bickle and Co., Plymouth, of which he was one of the managing directors, doing an extensive business in mining machinery for foreign mines, besides general engineering work at home. Among the many mechanical contrivances that he devised was the percussive rock-drill known by his name, of great simplicity and strength, to which was awarded a certificate of honour in the competitive trials at the International Exhibition of Mining and Metallurgy held at the Crystal Palace in 1890 (Proceedings 1891, page 144 and Plate 37). After that competition he carried out a series of experiments in rock-drilling machinery, resulting in further improvements of the Bickle drill. For some years he acted as consulting mechanical engineer to the St. John del Rey gold mines in Brazil; and in connection with his business had travelled in the mining districts of Canada, the United States of America, Mexico, South Africa, and other countries. His death took place in Plymouth on 9th February 1898, at the age of forty, from an acute attack of pneumonia. He became a Member of this Institution in 1892.

Edward Bicknell was born in 1849 in India. After being educated at the Taunton Grammar School, he served a three years' apprenticeship in the locomotive shops of the London and North Western Railway at Crewe, and was engaged as draughtsman in the office of an engineer at Taunton. In 1870 he went out to India as an assistant engineer on the Eastern Bengal Railway, where he had charge of the locomotive shops for two years. He was then engaged by the government in the Public Works Department as a mechanical engineer for the purpose of inspecting and reporting upon engines, boilers, and machinery; and was for some years employed in irrigation work on the Soane Canal. In 1875 he was sent on famine duty to the Bellary district. After holding his appointment for eight years, on the reduction of the Public Works staff he accepted the bonus offered and retired from the service, returning to England. In 1877 he went to Venezuela as locomotive superintendent, and took charge of the railway, and put the engines and rolling stock in proper working order, returning to England in 1879. In 1882 he went to India again, as contractor's agent and engineer on the Darjeeling, Himalayan, and Diamond Harbour railways for three years; and then took a contract for the construction of part of the Nagpur Bengal Railway, in partnership with Mr. Rumsey. On the completion of this railway he obtained another contract in Assam; but before the work was commenced his health broke down, and he returned to England in 1895. His death took place at Bath on 17th May 1898, in the forty-ninth year of his age. He became a Member of this Institution in 1883.

Charles Cochrane was born on 3rd May 1835 at Blackbrook near Dudley, being the eldest son of Mr. Alexander Brodie Cochrane, the principal proprietor of the Woodside Iron Works, near Dudley (Proceedings 1864, page 13). At the age of fifteen, after having been educated at a private school at Wilmslow in Cheshire, and while still too young to be admitted a student at King's College, London, he was nevertheless allowed to attend the college classes. There, besides a sound technical engineering education, he acquired under Professor Tennant the interest in geology which he maintained and utilised through life. On leaving college he spent some time in gaining practical experience under Mr. Samuel Holden Blackwell, the proprietor of the Russell's Hall Iron Works, near Dudley, and of other blast-furnaces, mills, and forges in the neighbourhood of Dudley and Bilston (Proceedings 1869, page 15). In 1855 he went for five years to the Ormesby Iron Works, Middlesbrough, then recently established by his father's firm; and on attaining the age of twenty-one he became a partner with his father in these works as well as in the Woodside Iron Works. On his father's death in 1863 he became joint owner of both these works with his brothers, as well as of their New Brancepeth Collieries in the county of Durham. On blast-furnaces he achieved the position of one of the greatest authorities, and was so recognised in the United States as much as in this country. To this Institution he contributed no less than nine papers on blast-furnace working and other subjects associated therewith, commencing in 1860 with a description of the method of taking off the waste gases from one of the Ormesby blast-furnaces with closed top and charging bell. As an original investigator and pioneer in blast-furnace economy he succeeded in establishing the soundness of his advanced views by the results of practical working. The ultimate success of the regenerative firebrick hot-blast stoves, embodying the principle originated by Sir William Siemens and developed in this direction by Mr. Edward A. Cowper, was largely due to his practical experience, and to his perseverance in making careful trial of the plan and maturing the details involved in its adoption. Having become a Member of this Institution in 1858, he was elected a Member of Council as early as 1864, and a Vice-President as early as 1872; and having exerted himself zealously in the interests of the Institution while the headquarters were in Birmingham, he did not permit their removal to London in 1877 to diminish his activity in furtherance of its welfare. In 1889 he was elected President; and during the year of his presidency he devoted himself unsparingly to the duties of the office, thereby increasing the regret felt by the members that his own health, with his anxiety for that also of his son, precluded his continuing President for a second year. His presidency was signalised not merely by an address of remarkable originality and comprehensive scope (Proceedings 1889, page 208), but also by the last of his admirable series of blast-furnace papers (page 589), in which he presented the successful results of his own latest blast-furnace practice with lime instead of limestone as flux. As a single illustration of the versatility of his mind, perhaps no better instance could be quoted, apart from his presidential address in 1889, than the concise and apposite remarks he made when presiding at the Paris meeting in the same year, upon so abstruse a subject as the rationalization of Regnault's experiments on steam, in connection with Mr. J. Macfarlane Gray's able elaboration of the theta-phi or temperature-entropy chart (Proceedings 1889, pages 451–2). Among the large structures emanating from the Woodside Iron Works during his association therewith may be mentioned in London the Holborn Viaduct, Westminster Bridge, Cannon Street Railway Bridge and Station, and Charing Cross Railway Bridge and Station. His firm also erected for the London and North Western Railway the Runcorn Bridge over the Mersey; and they removed the Hungerford Suspension Bridge over the Thames, and re-erected it as the Clifton Suspension Bridge at Bristol, strengthening it as required for its new position. It was to the Iron and Steel Institute, of which also he was a member, that his final paper on the relative merits of limestone and lime in blast-furnace practice was contributed, and discussed in his absence on 6th May 1898, when he was already on his death-bed after an illness confining him to the house from the commencement of the year. His death took place on 11th May 1898 at his residence, Green Royde, Pedmore, near Stourbridge, at the age of sixty-three. In the movement for the incorporation of Dudley he took an active part, and was a member of the first town council, and second mayor of the borough in 1866; and to the educational and other public interests of the district he devoted much time and energy. He was a justice of the peace for the counties of Worcester and Stafford; chairman of Cochrane and Co., and of Cochrane, Grove and Co.; and a partner in Cochrane and Co., Woodside Iron Works, Dudley.

The Hon. Francis Fleetwood Eden, son of the fourth Baron Auckland, was born at Doncaster on 16th February 1865, and educated at Charterhouse School, Godalming. From 1881 to 1886 he served his time under Mr. Patrick Stirling in the locomotive works of the Great Northern Railway at Doncaster, and afterwards worked as journeyman fitter and locomotive foreman at the Peterborough works of the same railway. From June 1888 he was employed by the Buenos Aires Great Southern Railway as inspecting engineer for the erection and working of the automatic vacuum brake. In January 1890 he was appointed manager of the workshops of that railway in Bahia Blanca, with charge of the hydraulic machinery on the wharf in that port and of the locomotive working of the southern section of the line. His death took place at the British Hospital, Montevideo, on 22nd March 1898, at the age of thirty-three. He became a Member of this Institution in 1893.

PHILIPPE ALEXANDRE GOTTSCHALK was born in St. Petersburg on 13th August 1834, his father being Danish and his mother French. In 1843, when nine years old, he came to Paris, and after being educated at the Louis-le-Grand Lyceum became a student from 1850 to 1853 in the Ecole Centrale, obtaining there a first-class diploma. In 1854 he commenced his career as an engineer in the service of the Southern Railway under Messrs. Flachat, Clapeyron, and Lechatelier, by whom he was sent next year to England to order and inspect and pass rails and permanent way of the combined Brunel and Barlow pattern, which was then adopted on the Southern lines. Returning to France in 1855 he was engaged for two years under M. Eugène Flachat on the various works which attended the amalgamation of the different lines forming the Western Railway. From October 1857 to 1866 he was engineer to the Russian Railways, which at that time were under the direction of a board in Paris, with M. Collignon as director general; and he rapidly rose to the position of engineer-in-chief, which he held at the opening in August 1862 of the last section of the Moscow and Nijni-Novgorod Railway, having had to design the whole of the stations &c. for this and for the St. Petersburg and Warsaw Railway, together 1,100 miles long. From 1863 to 1866 he had charge of the equipment with rolling stock of the Nicolas Railway from St. Petersburg to Moscow, 370 miles long, acting on behalf of Messrs. Cail and the

Fives-Lille Co. From 1867 to 1878 he was appointed by Messrs. Talabot and Desgrange to succeed the latter as engineer and locomotive superintendent of the Austrian Southern Railways, which form an integral part of the Lombardy Railways, and are still under the direction of a board in Paris. A remarkable instance of his pertinacity in insisting upon what he believed justice to require, and at the same time of his generosity, occurred early during this twelve years' period, in connection with the agreement whereby he was to receive a percentage on the saving he might effect in the working expenses. The florin having since declined in value, he claimed an amount based on its original value at the date of the agreement; the board, though impressed by the force with which the claim was urged, declined to accede thereto, and he had to bow to their decision; the next day he presented to the workmen's schools at Marburg, established by the company, the whole of the sum he had claimed on the higher scale, amounting to about £1,200. The network of lines under his management comprised about 1,400 miles, including the Sommering and Brenner passes, and on his leaving in 1878 were worked by 1,275 locomotives, 3,353 passenger carriages, and 25,927 wagons; a considerable portion of these had been built in the company's shops at Vienna and Marburg, and the economy he effected was all the more remarkable as following upon the important saving previously brought about by his able predecessor. M. Desgrange having issued notes on the working of the Sommering incline, M. Gottschalk followed up the idea by yet more extensive notes on that of the Brenner incline of 1 in 40, which crossed the Alps between Innsbruck and Bozen at an elevation of 4,480 feet; for this incline he designed a class of locomotive which was adopted also for the Mont Cenis line, then worked by the Lombardy Railways Co. For these notes he was awarded in 1876 the gold medal of the Société des Ingénieurs Civils. Returning to France in 1878, he was elected in 1879 a Vice-President and in 1880 President of the Société des Ingénieurs Civils. Owing to the leading part he took in the discussions during his presidency upon the subject of the purchase of the railways, he was appointed on 25th November 1880 a member of the government Railway Commission. In the same year he became naturalised as a Frenchman. In April 1881 he was appointed a member of the Improvement Committee of the Ecole Centrale, and was also elected President of the Fellowship Association connected therewith. In January 1882 he was appointed by the Ministry of Public Works to be a member of the Consulting Committee for the technical working of railways. In connection with the latter and with the Railway Commission, he was occupied during the remaining eighteen years of his life with a large number of practical investigations, in all of which he took a leading part. On 12th July 1890 he was created an Officer of the Legion of Honour. He was consulting engineer to the Bank of Paris and the Netherlands, and to the Austro-Hungarian State Railways, and was concerned in establishing the Association of Iron and Steel Works in the north and east of France. He became a Member of this Institution in 1880; and on the occasion of the meetings held in Paris in 1878 and 1889, his early acquaintance with England was highly appreciated by those who were so fortunate as to come in for his welcome and cordial greetings. His death took place in Paris on 21st February 1898 in the sixty-fourth year of his age.

JOSEPH WHITWORTH HULSE was born at Withington near Manchester on 24th August 1861, being the second son of the late Mr. William Wilson Hulse (Proceedings 1897, page 137). He was educated at Uppingham School, and in 1876 began his apprenticeship to his uncle, Mr. Joseph Sykes Hulse, at the Ordsal Works, Salford. On the death of his father, who had succeeded his uncle in 1881, he became the proprietor of these works in 1897. In machine-tools he introduced several improvements; and also in calico-printing machinery, which was made by his firm in combination with machine-tools. During the engineering strike in the latter half of 1897 he took an active part in the management of the local branch of the employers' federation, of which he was appointed joint representative with the late Colonel Dyer. His death took place at Didsbury near Manchester on 20th April 1898 in the thirty-seventh year of his age. He became a Graduate of this Institution in 1883, and a Member in 1890.

Thomas Rees Morgan was born at Penydarran, Merthyr Tydfil, on 31st March 1834, being the youngest of a family of six children. When eight years old he went to work in a coal mine, in which two years later he was run over by a number of loaded coal wagons, the accident resulting in the loss of his left leg at the knee. He was then sent to school for three years to Mr. Taliesin Williams, the father of his life-long friend the late Edward Williams (Proceedings 1886, page 264). At the age of fourteen he left school, and served an apprenticeship of five years in the machine shop of the Penydarran Iron Works; after which he had charge for five years of the large machine shops at Messrs. Maybrey's works, Llanelly. In 1865 he emigrated with his family to the United States, and after a brief engagement in the shops of the Lackawanna and Bloomsburg Railroad at Pittston, Pennsylvania, he went to the Cambria Iron Works at Johnstown, and thence to Pittsburg, where he was engaged first as foreman in the machine shops of the Allegheny Valley Railroad, then as machinist in the Atlas Works, next as superintendent of Smith and Porter's machine works, and finally as master mechanic in the Atlas Works. In February 1868 he started business for himself in Pittsburg, manufacturing steam-hammers and other special machinery. After being carried on here for three years, the business had grown so rapidly that in August 1871 he removed to Alliance, Ohio, where he organized the Morgan Engineering Company, employing at first about twenty mechanics. At the present time employment is given to about six hundred trained workmen. The articles manufactured are mostly of his own designing, many of them being specially produced to meet ever-varying requirements. They include over a thousand steam-hammers for general forging and for forging steel, drop and helve hammers worked by steam, hydraulic machinery, electric travelling cranes, and electric punching and shearing presses, from the smallest to the largest sizes used in the country. The 80-ton hammer used in the Midvale Steel Works, and weighing 900 tons, was made by him; as was also the 120-ton special overhead crane for serving the hammer. He was a pioneer in the manufacture of hydraulic machinery, which he supplied to all the shipyards in the United States. He was also the first to construct electric travelling cranes, of which he built over a thousand for various works. In the different sections of the Carnegie Steel Works alone there are eighty-five large travelling cranes designed and constructed by him. Two travelling cranes, each capable of lifting 150 tons, were designed and erected in the navy yard at Washington and in the Watervliet Arsenal at West Troy. Among other heavy machinery turned out from his works are fifty steam plate-shears, with blades from 100 to 135 inches long, for shearing cold steel plates up to 2 inches thickness, each machine weighing from 75 to 200 tons; and one hydraulic shearing press, believed to be the largest ever built, having a power of 3,500 tons, which has sheared with ease steel blooms 42 inches wide by 23 inches thick. The first successful automatic disappearing gun-carriage for firing all round a complete circle, known as the Gordon-Morgan disappearing gun-carriage, was built in his works; it weighs about 300 tons. Three of these carriages were built by him for the government within the past three years. In 1882 he was instrumental in organizing the Solid Steel Co. of Alliance, of which he was president until 1889; from this concern arose the combination of steel-casting manufacturers known as the American Steel Casting Co. His death, which took place suddenly from failure of the heart on 6th September 1897, in the sixty-fourth year of his age, is attributed to his anxiety for the recovery of his wife, and his devoted attention to her during a dangerous illness extending over the four months preceding. He became a Member of this Institution in 1885, and was also a Member of the American Society of Mechanical Engineers, and of the Iron and Steel Institute. At the time of his death he occupied also various positions of influence and trust in Alliance.

John Philipson was born in Newcastle-on-Tyne on 19th October 1832, being a son of Mr. George Hare Philipson, coachbuilder, who was one of the early members of this Institution, and built at that time a number of railway carriages. After having received his education in a private academy in the town, he served his apprenticeship to his father's firm, Messrs. Atkinson and Philipson, as a coach-body maker, a coach smith, an axle turner, and a mechanical draughtsman.

Subsequently, in order to gain further experience, he went for a time to Messrs. Briggs and Co., carriage builders in London. Returning to the Newcastle works, he superintended the erection of lathes for iron and wood turning, and introduced many improvements in machinery to reduce labour in making wheels, springs, and axles. In 1856 he became managing partner, and in 1864 succeeded his father in the business, which he carried on with his brother till 1873, when he became the sole proprietor. He was the author of standard works on coach-body making, on harness, and on the art and craft of coachbuilding. He invented a carriage spring, having a receptacle formed in each end to contain a rubber cushion; also rubber cushions to lessen the rattle of carriage windows; and a convertible carriage, in which the underworks were made separate from the body, so that one undercarriage might be used with two, three, or four different kinds of bodies. His designs for parcel-post vans were adopted by the Postmaster General, and he received the honorary title of designer to the Post Office. He also did a quantity of government work in the shape of prison vans and ambulances. During the past three years, in conjunction with Messrs. Toward and Co., engineers, Newcastle, he had produced some trustworthy workable steam road-carriages; the first of them performed well during recent trials at Liverpool; and the fifth, as yet in course of construction, is a heavy wagon to carry three tons up a steep incline. With his name is associated the modification of the carriage tax; regarding this as the last remaining tax upon industry, he laboured hard for ten years to secure its abolition. His death took place at his residence in Newcastle on 24th June 1898, in the sixty-sixth year of his age, from syncope following upon an attack of influenza. He became a Member of this Institution in 1881.

John Rawlins was born at Uttoxeter, Staffordshire, on 15th November 1836. In 1851 he entered the railway carriage and wagon works of Messrs. Johnson and Kinder at Bromsgrove, passing through the usual routine of shops and offices. In 1856, after the business had been removed to Oldbury, near Birmingham, he became head draughtsman and chief assistant to the general manager, Mr.

William Stableford (Proceedings 1887, page 277). In 1866 he was appointed deputy manager of the Metropolitan Railway-Carriage and Wagon Works, Saltley; in 1871, on the retirement of Mr. Henry Brown (Proceedings 1892, page 98), he succeeded him as general manager; and in 1896 he was elected upon the board of directors as managing director. He possessed a thorough knowledge, both theoretical and practical, of the business of building railway carriages and wagons. His death took place at his residence at Erdington near Birmingham on 22nd May 1898 at the age of sixty-one, after an illness of only three days. He became a Member of this Institution in 1872.

JOHN RICHARD SCHRAM was born at Upsala, Sweden, on 6th February 1834, and studied at the Academy of Fine Arts in Stockholm. In 1852–4 he was engaged on the Köping Hult Railway, Sweden, first under Mr. Watson and afterwards under Mr. Cronin. In 1854–6 he superintended the repairs of Upsala Cathedral. In 1856–7 he travelled in England, Germany, France, and Belgium. In 1858–66 he superintended the marble works at Singo, Sweden, for which he designed and erected the machinery; and in 1867 travelled abroad again. In 1868 he acted as a consulting engineer in Stockholm. In 1869 he was engaged as draughtsman at the South Kensington Museum, London. In 1870 he introduced the Burleigh rock drill in Sweden; and in 1871–4 the same drill with air compressors in Austria and Hungary. In 1877 he started business in London as a mechanical engineer, and thenceforth was occupied principally in the design and construction of rock drills and air compressors for tunnelling and mining. Amongst the works for which these were supplied were the Khojak tunnel, the Indian State Railway tunnels, the Natal State Railways, the Imperial Railways of Japan, and the Periyar Irrigation Works in the Madras presidency. During the last four years he introduced and perfected the "Optimus" compound rock-drill, which was the first of its kind and effects a great saving in compressed air by working on the compound principle. His death took place at Lucerne, Switzerland, on 20th April 1898 at the age of sixty-four. He became a Member of this Institution in 1880.

Sir John Smith was born at Ashby-de-la-Zouch on 26th August 1822. In due time he became apprenticed to Mr. Prosser, a brassfounder in Derby; and shortly after completing his apprenticeship he started there on his own account in St. Mary's Gate, having acquired the brassfounding business of Mr. Henry James. By the excellent quality of his castings he soon secured the confidence of some of the largest engineering establishments in the country, especially those of the Midland Railway, the North Staffordshire Railway, the Gloucester Wagon Works, the Admiralty, and the large marine engineers on the Thames, besides many collieries and ironworks. At first he was engaged chiefly in the production of gun-metal and brass castings; but on removing about 1858 to larger premises in Traffic Street and Siddals Road he began the machining of all kinds of gun-metal and brass work for engines, breweries, and other purposes. On the adoption at Messrs. Bass and Co.'s brewery, Burton-on-Trent, of what is technically known as the Burton Union system of fermentation, he was entrusted with the manufacture of the whole of the brass valves and fittings; and for Union casks his attemperator was adopted to the extent of many thousands, which enables the brewer to regulate the temperature of the beer during fermentation. About 1858 also he undertook the sole manufacture of Mr. James Roscoe's lubricator for steam cylinders, which he modified and perfected, and of which upwards of 20,000 have been made. For a number of years he was also the sole maker of Jacobs' cask-washing machine; and he himself devised a useful racking apparatus for filling casks without the risk of overflowing, which has been largely adopted. In 1860 he opened a complete branch establishment at Burton-on-Trent, for dealing conveniently and promptly with urgent work for the large breweries of the town. After having extended his business on a wide basis, he retired in 1886 from the active management, while continuing a busy man in municipal and other public affairs. During the year of his mayoralty he entertained the Prince and Princess of Wales on their visit to Derby in December 1872 to distribute the prizes at Derby School, of which he was a governor. In 1887 he received the honour of knighthood. His death took place at his residence in Derby on

10th December 1897 in the seventy-sixth year of his age, after his health had for some time previously been failing. He became a Member of this Institution in 1860, and was a frequent attendant at the summer meetings, his last appearance having been at the Birmingham Jubilee Meeting in 1897 (Proceedings, page 280).

John Charters Spence was born in Belfast on 28th July 1868, being the eldest son of Rev. John Spence, D.D. After receiving his education 1878–84 at St. John's College, Leatherhead, and King Alfred's School, Wantage, he served his apprenticeship 1884–9 with Messrs. D. and W. Grant, York Street Foundry, Belfast. For about two years 1889–91 he acted as assistant to Mr. A. Basil Wilson, Holywood, during which time he made two voyages to sea as engineer. For nearly two years 1891–3 he was draughtsman with Messrs. Workman, Clark and Co., Belfast; and then about six months with Messrs. Victor Coates and Co., Belfast, as draughtsman in special charge of erecting two sets of large mill engines. In 1893 he became assistant manager in the engineering works of Messrs. Thomas Begbie and Co., Johannesburg, employing about 300 workpeople; and in 1896 he was appointed to full charge of the works. His death took place on 27th March 1898 at the age of twenty-nine, after a long illness from a chest affection. He became an Associate Member of this Institution in 1897.

Frederick William Stoker, son of Rev. F. Stoker, vicar of Pittington near Durham, was born on 12th October 1848 at Pittington, and was educated at the Durham College School up to the age of sixteen, when he was apprenticed in the works of Messrs. Palmer at Jarrow. There he served his time for five years, and afterwards remained for some two years longer, making several trips in the engine room of various of their steamers, and holding the position of engineer draughtsman in the rolling mills department. About 1870 he became the mechanical engineer to The Moor Iron Works of Messrs. Shaw Johnson and Reay, Stockton-on-Tees, of which he had the entire management, producing at that time from 700 to 800 tons of iron rails per week. Here he designed and erected a complete rolling mill both for rails and for plates, being one of the first to adopt the plan of three-high rolls for rolling long rails of light sections, and larger plates than were then in vogue. Amongst other improvements he introduced there a saw of his own invention for cutting blooms of large size, whereby a considerable saving was effected in the cost of manufacture of rails. Latterly he was also in charge of the engineering department of the firm's three collieries at Whitworth near Spennymoor, Hamsteels near Durham, and Castle Eden, all of which he equipped with a considerable amount of modern machinery of his own design. In 1882 he returned to Messrs. Palmer's Works, Jarrow, as manager of the rolling mills and steel works department, where again the heavy machinery erected was from his designs. Leaving Jarrow in April 1887, he became general manager of the Bowling Iron Works near Bradford. In 1888 he was appointed general manager of the Erith Iron Works of Messrs. Easton and Anderson, and remained there until the spring of 1892, when, after a visit made for his health, he settled in Johannesburg as a consulting engineer, representing this and several other English firms. There he acquired a large practice, in connection especially with coal mining; at the Cassel Colliery and the Natal Navigation Collieries he greatly increased the mechanical appliances, and also designed and ordered large quantities of other machinery in the Rand district; he was a director of several other concerns. His death took place at Johannesburg on 22nd January 1898, in the fiftieth year of his age, from a severe attack of dysentery complicated with other maladies. He became a Member of this Institution in 1875.

William George Strype was born in Liverpool on 12th January 1847. After being educated in Drogheda he served his time with Messrs. Thomas Grendon and Co., Drogheda, with whom he afterwards acted as manager. He became a Member of this Institution in 1873, at which time he was engineer to Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. In 1874–6 he was manager of the Custom-House Flour Mill, Dublin. Removing in 1877 to Wicklow, where he resided till 1887, he was concerned in the manufacture of sulphuric acid from Irish pyrites obtained from the sulphur ore mines near Ovoca, of which he gave a description in 1879 to the Institution of Civil Engineers of Ireland (Transactions, vol. 12, page 152). He also took up the prevention of waste and misuse of water in Wicklow; and the use of well tubes for subaqueous trial borings with a view to foundations under water. In 1888 he returned to Dublin. He carried out successfully several waterworks for the supply of different towns in Ireland, and also various drainage works, notably the main drainage of Blackrock and Kingstown in county Dublin. He was a Member of the Institution of Civil Engineers, and also of that in Ireland. His death took place in Dublin on 14th March 1898 at the age of fifty-one.

Joseph Westwood was born at Bow, London, on 18th November 1844. In 1860 he entered the London Yard Iron Works of his father's firm at Poplar, and spent about four years in passing through the various shops and drawing office. From 1864 to 1879 he had responsible charge of the engineering departments of the works, during which time various large viaducts, bridges, railway station roofs, engines for gas works, and many varieties of engineering ironwork were constructed, some of them from his own designs. Retiring about 1881 from his father's firm, he took offices in London for a time; and on his father's death in 1883, he determined to start new works with more modern machinery and appliances for constructing ironwork and steelwork of every kind. The site he selected was that of the old Napier Works at Millwall, where Fairbairn had erected in 1836 the earliest iron-shipbuilding establishment of any magnitude in England and had made the test tubes for the Britannia Bridge, where Napier had built many vessels, and where Scott Russell had built for Brunel the Leviathan or Great Eastern. These works he altered extensively, covering with buildings and sheds an area of nearly six acres, with a frontage of about 500 feet to the Thames, and a width of about 550 feet from the river to the road. About two years ago adjoining premises were added, which are connected with the railway system of the country, and have a covered area of about three acres; the total area of the works thus enlarged is about nine acres. Here has been carried out a large quantity of work for the India Office, the Crown Agents for the Colonies, numerous Indian and Colonial railways and public works, as well as for many railways in the United Kingdom and for private firms. His death took place at Hampstead, London, on 18th April 1898 at the age of fifty-three. He became a Member of this Institution in 1880; and was also a Member of the Institution of Civil Engineers, the Institution of Naval Architects, and numerous other scientific societies.

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WIGGLESWORTH, F., elected Associate Member, 3.
WILLIAMS, N. C., elected Graduate, 3.
WILSON, Sir A., Bart., created Baronet, 4.
WILSON, D. E., elected Associate Member, 3.
WILSON, J. C., elected Associate Member, 3.
WILSON, R., Memoir, 139.
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WINN, C. R., elected Member, 142.
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Fig. 1. *Number of Passengers carried each Year by Railways of the United Kingdom since 1854. Taken from Board of Trade Returns.*

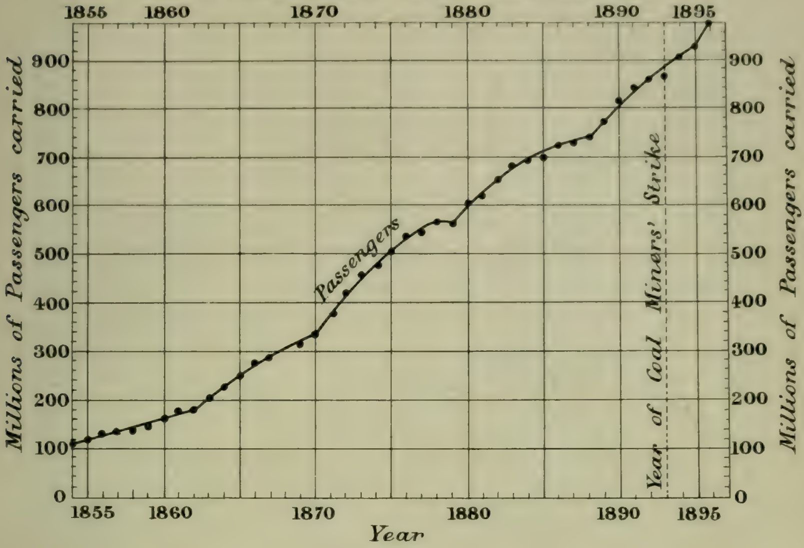


Fig. 2. *Number of Passengers carried each Year by the Midland Railway since 1861. Taken from Board of Trade Returns.*

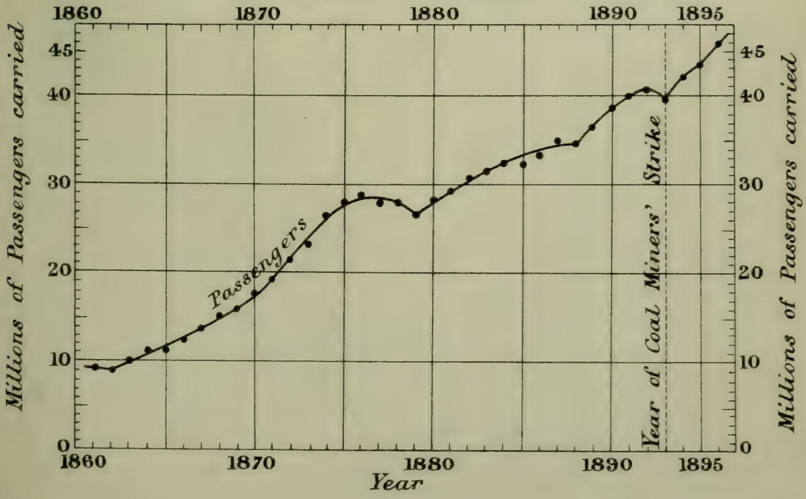


Fig. 3. *Goods and Minerals carried each Year by Railways of the United Kingdom.*

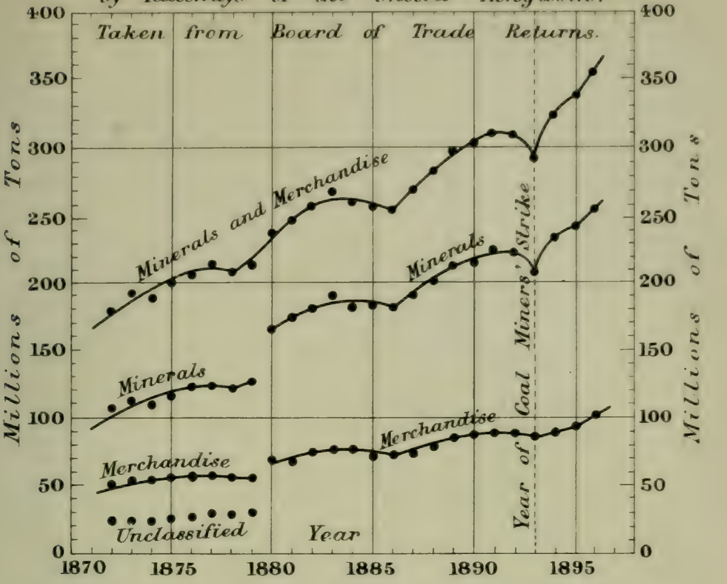


Fig. 4. *Goods and Minerals carried each Year by the Midland Railway.*

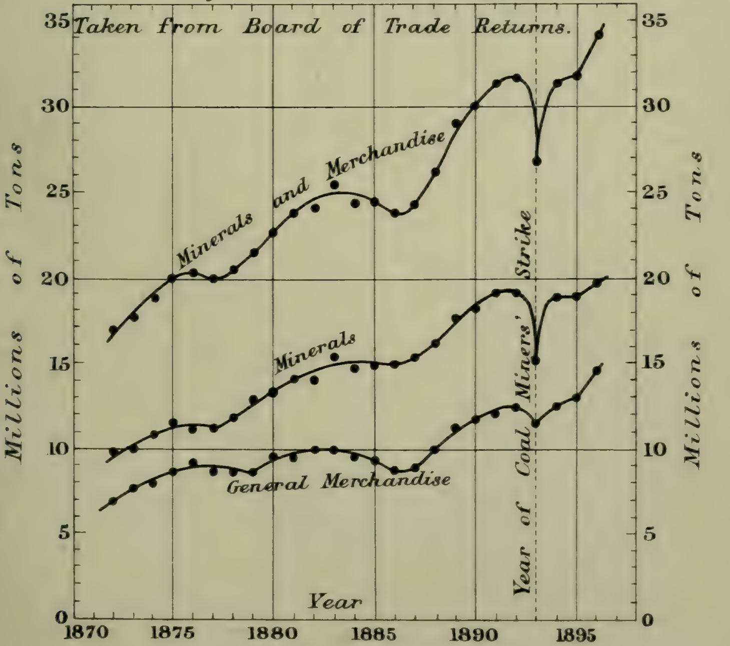


Fig. 5.

United Kingdom Train Mileage Statistics.

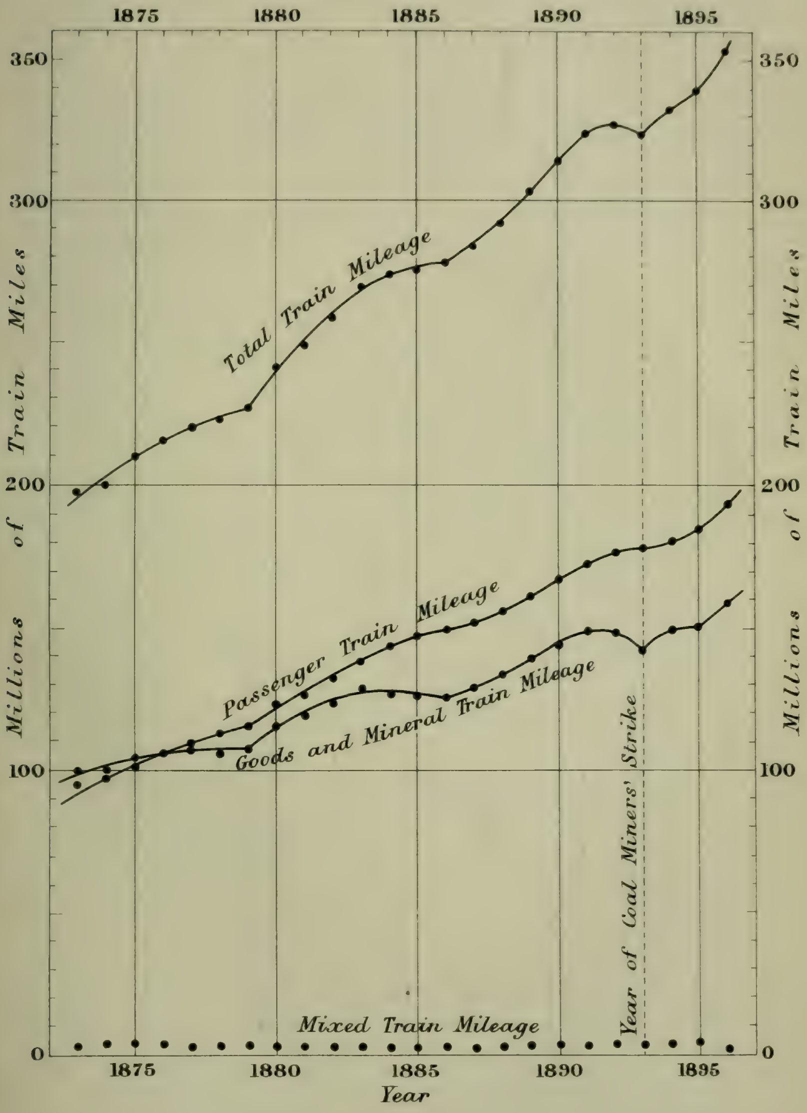


Fig. 6.

Midland Railway Mileage Statistics.

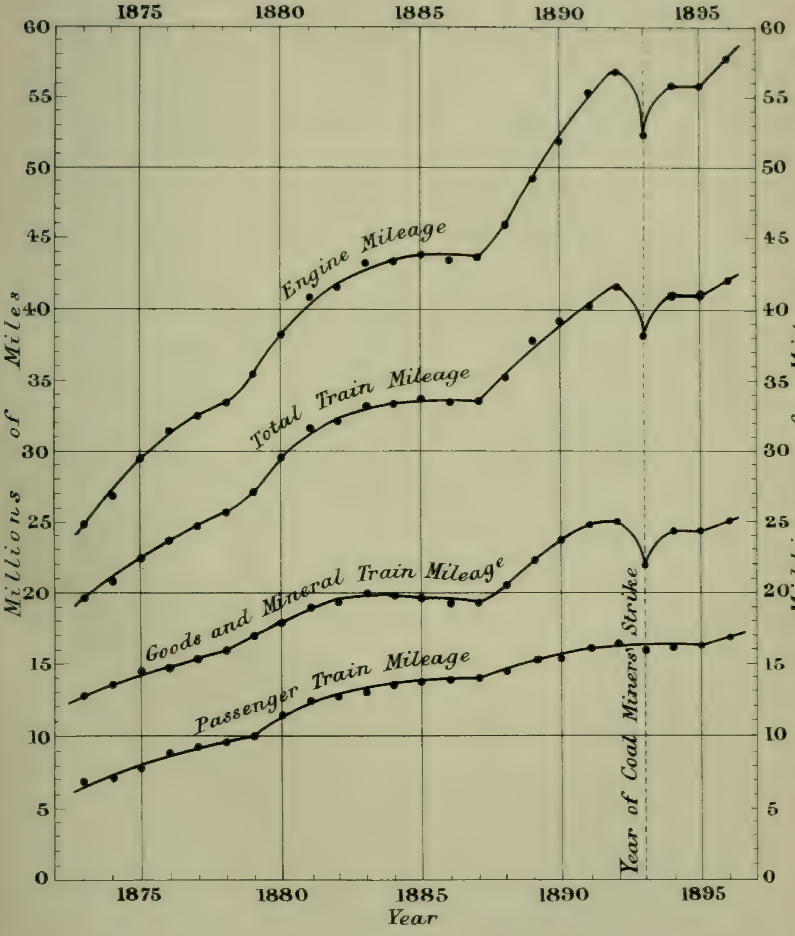


Fig. 7. *Goods and Minerals carried per Train Mile.*

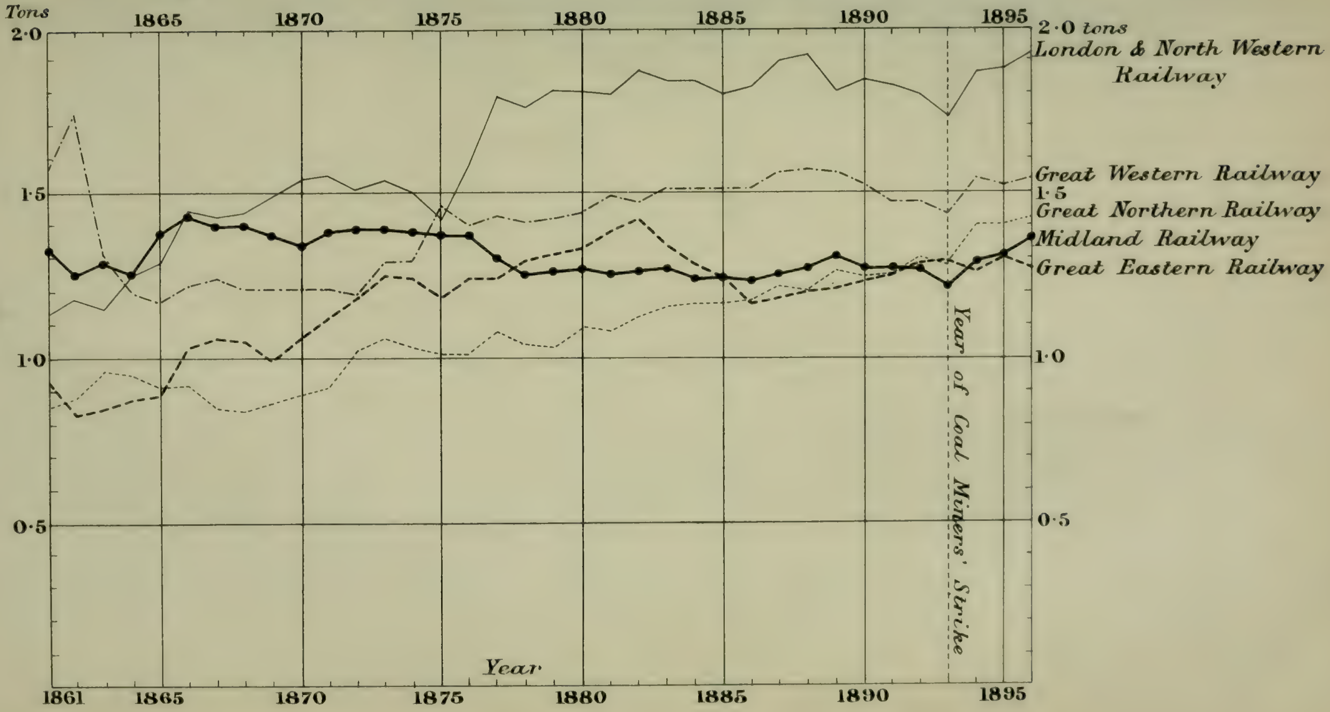


Fig. 8. *Goods and Minerals carried per Train Mile.*

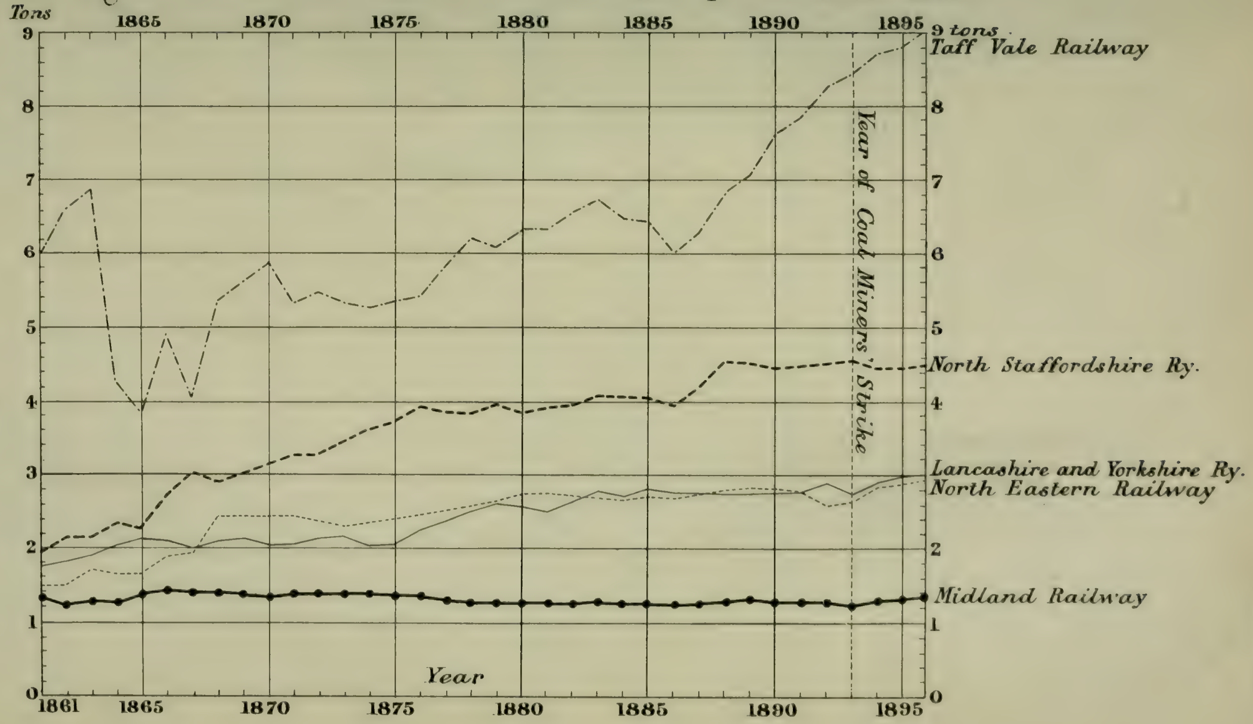
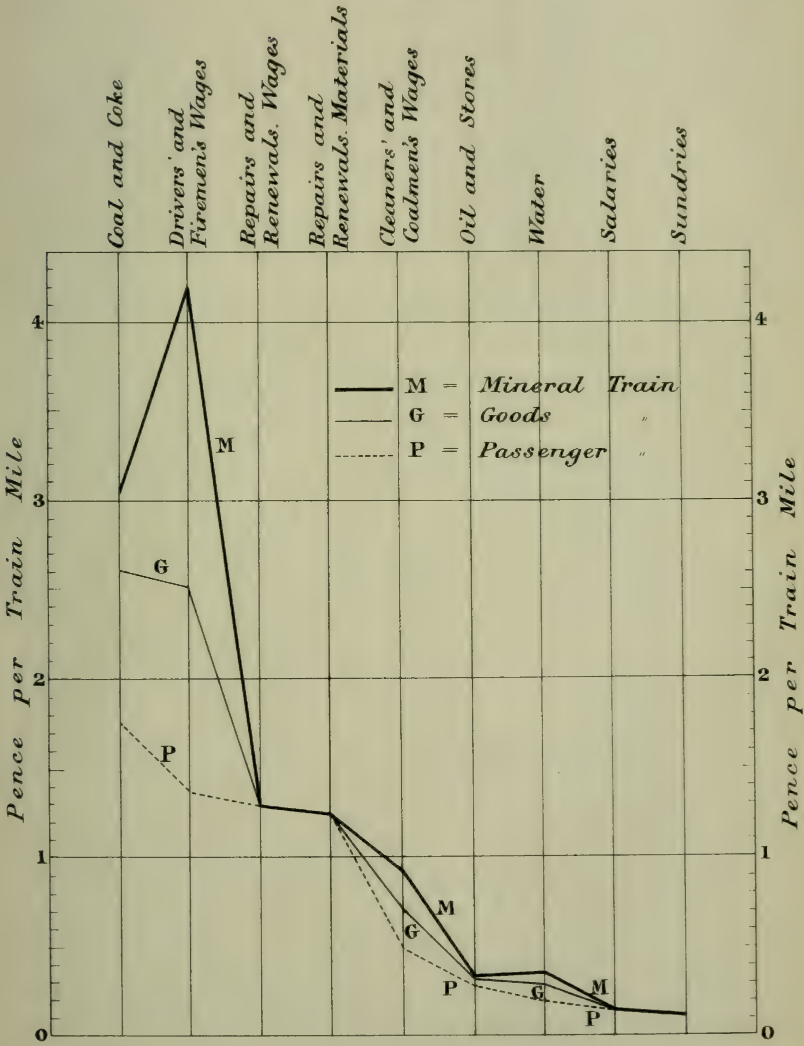


Fig. 9.

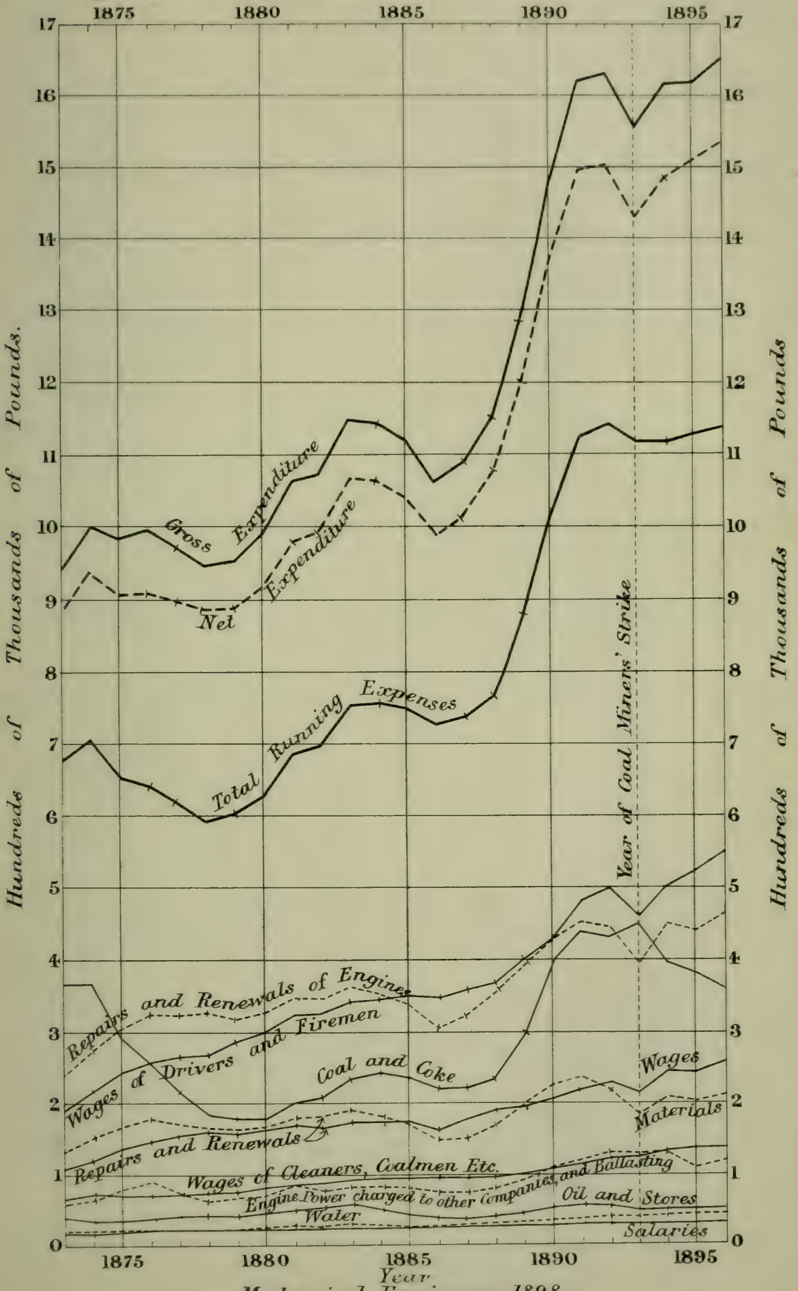
Midland Railway.

Estimated cost per Train Mile
of working Passenger, Goods, and Mineral Trains, 1892.
(Power only.)



Midland Railway.

Fig. 10. *Locomotive Department Expenditure.*



Midland Railway.

Fig. 11. *Locomotive Department Expenditure per Train Mile.*

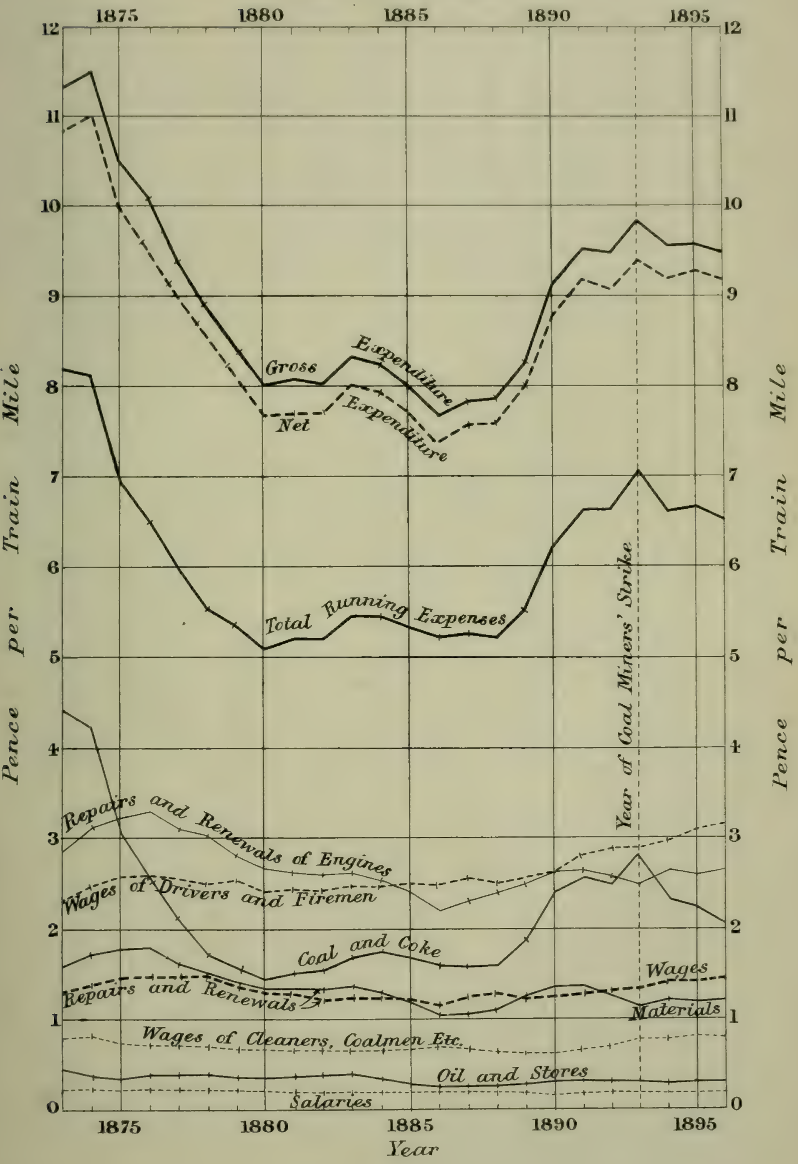


Fig. 12.

Locomotive Stock.

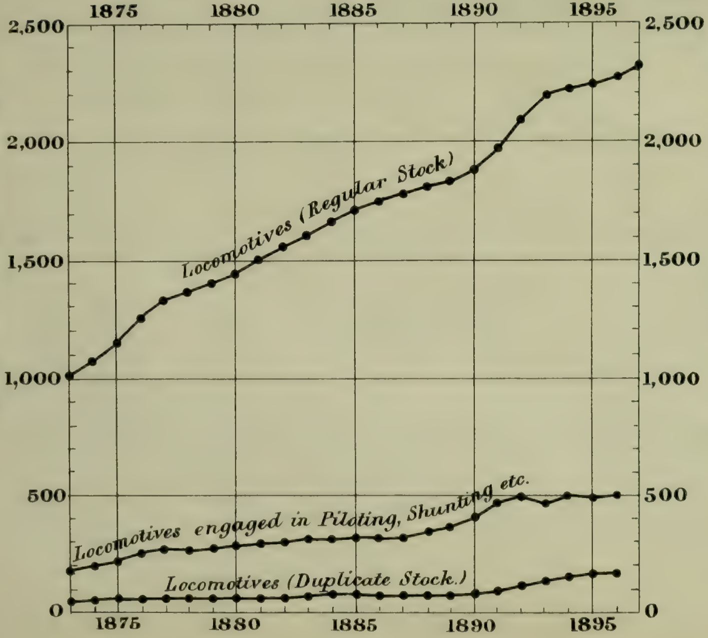
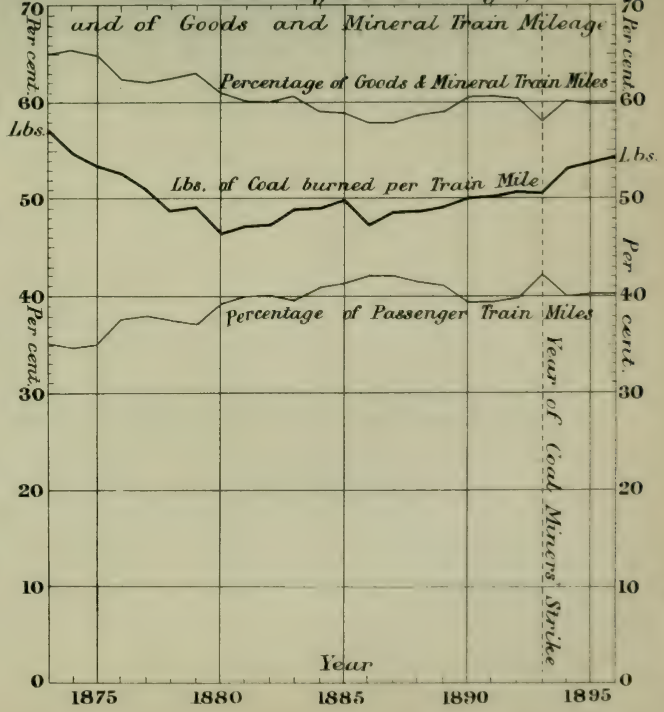


Fig. 13.

Midland Railway. Coal consumption per Train Mile in lbs.; and Percentages of Passenger, and of Goods and Mineral Train Mileage



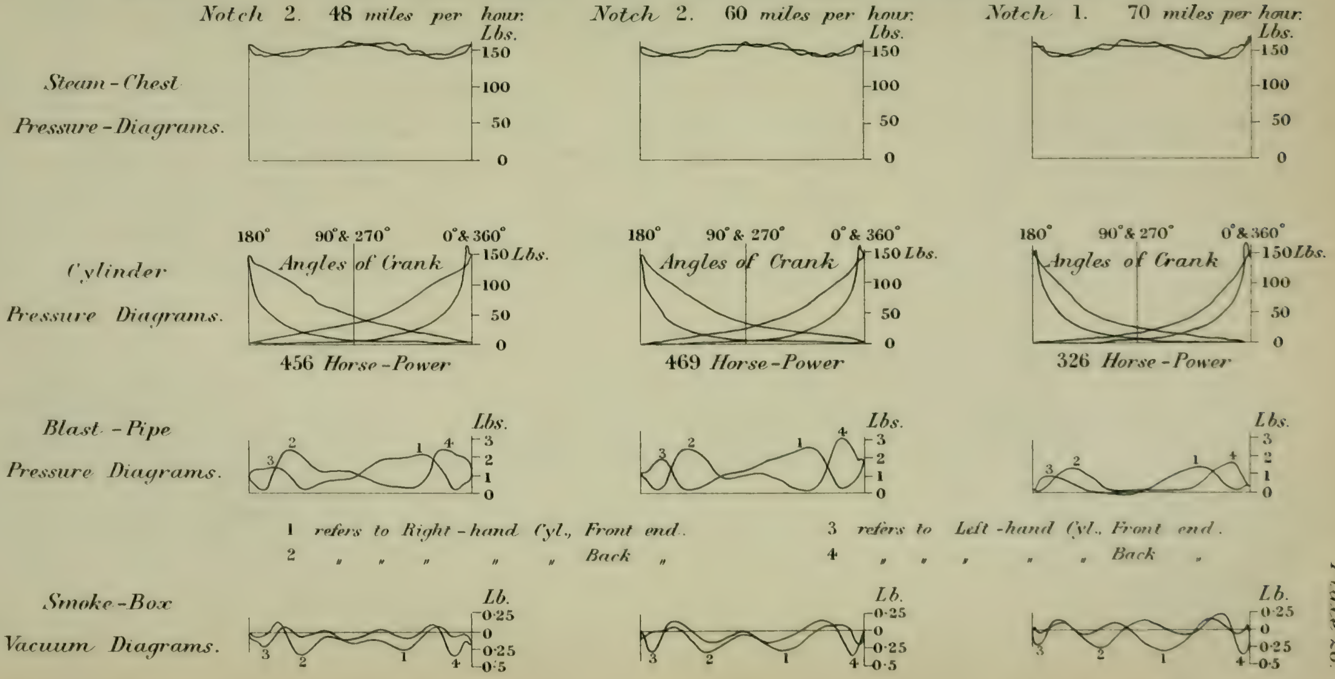


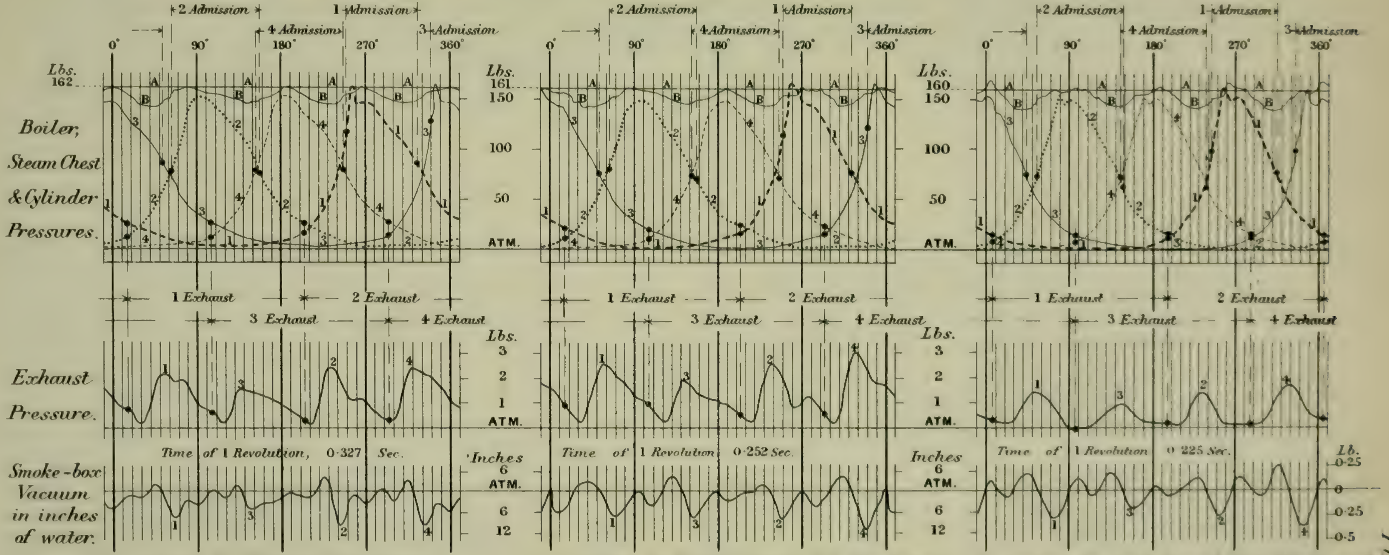
Fig. 14. *Locomotive Indicator Diagrams*

taken from Engine No. 26 whilst working London and Nottingham Express Trains.

Plate 28.

PRESIDENT'S ADDRESS.

Fig. 15. *Locomotive Indicator Diagrams showing changes of Pressure during equal Time intervals.*



Notch 2. 48 miles per hour. One revolution of crank.

Notch 2. 60 miles per hour. One revolution of crank.

Notch 1. 70 miles per hour. One revolution of crank.

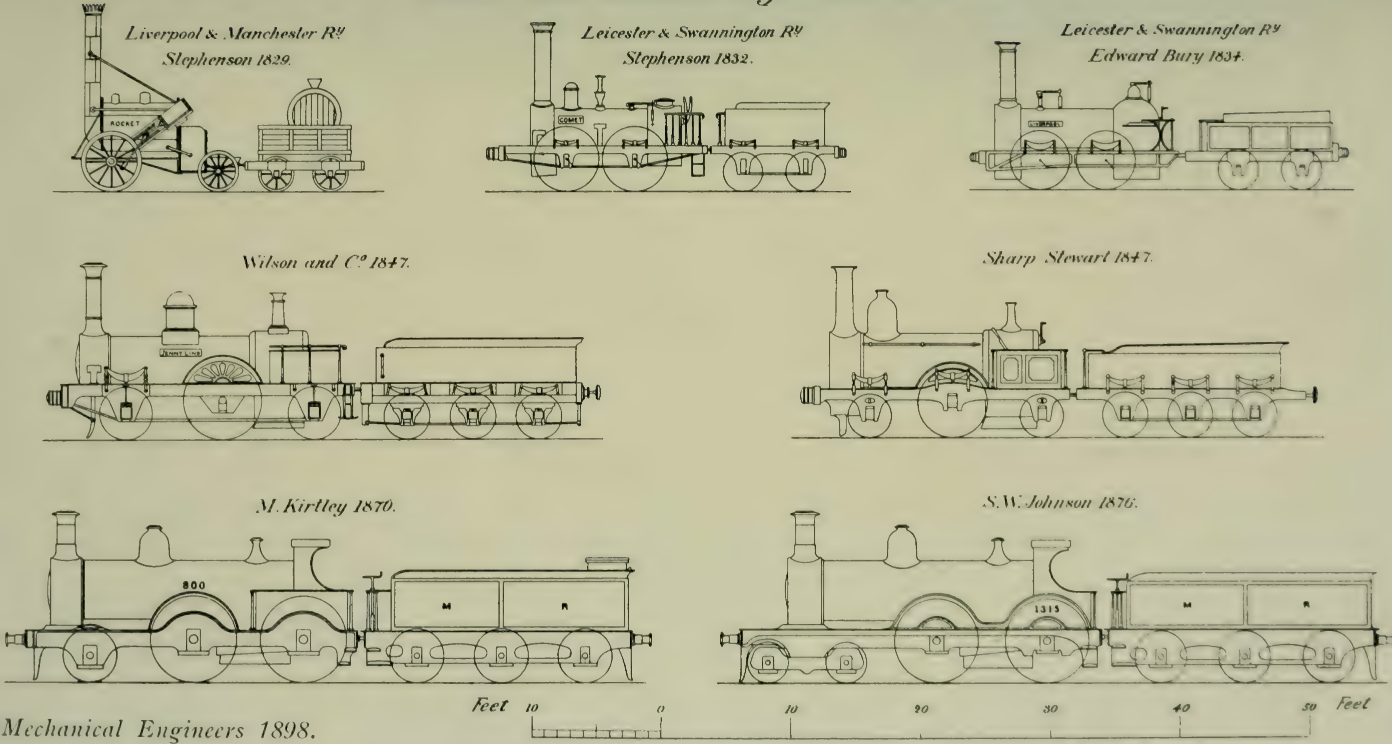
A *refers to Boiler Pressure.*
B *" " Steam-Chest Pressure.*

1 *refers to Right-hand Cyl. Front end.*
2 *" " " " " Back "*

3 *refers to Left-hand Cyl. Front end.*
4 *" " " " " Back "*

Plate 29.

"Rocket," and Midland Engines 1832 to 1876.


Liverpool & Manchester Ry Stephenson 1829.

Leicester & Swannington Ry Stephenson 1832.

Leicester & Swannington Ry Edward Bury 1834.

Wilson and Co 1847.

Sharp Stewart 1847.

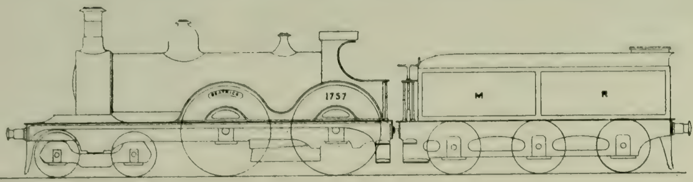
M. Kirtley 1870.

S.W. Johnson 1876.

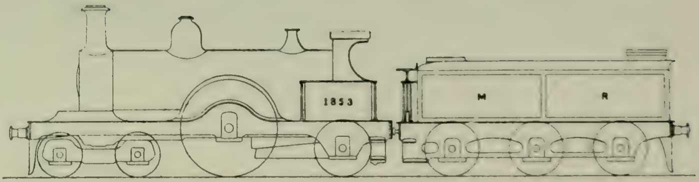
Plate 30.

Midland Engines, 1886 to 1897.

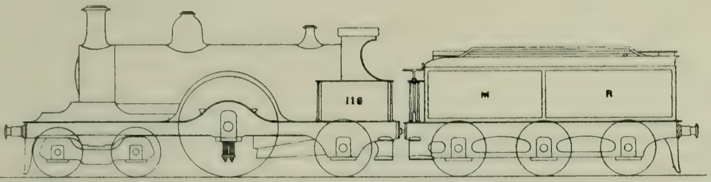
S.W. Johnson, 1886. Gold Medal, Saltaire Exhibition.



S.W. Johnson, 1889. Grand Prix. Paris



S.W. Johnson, 1896



S.W. Johnson, 1897

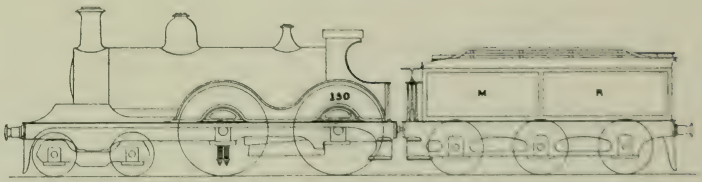


Plate 31.

Midland Passenger Vehicles, 1839 to 1874.

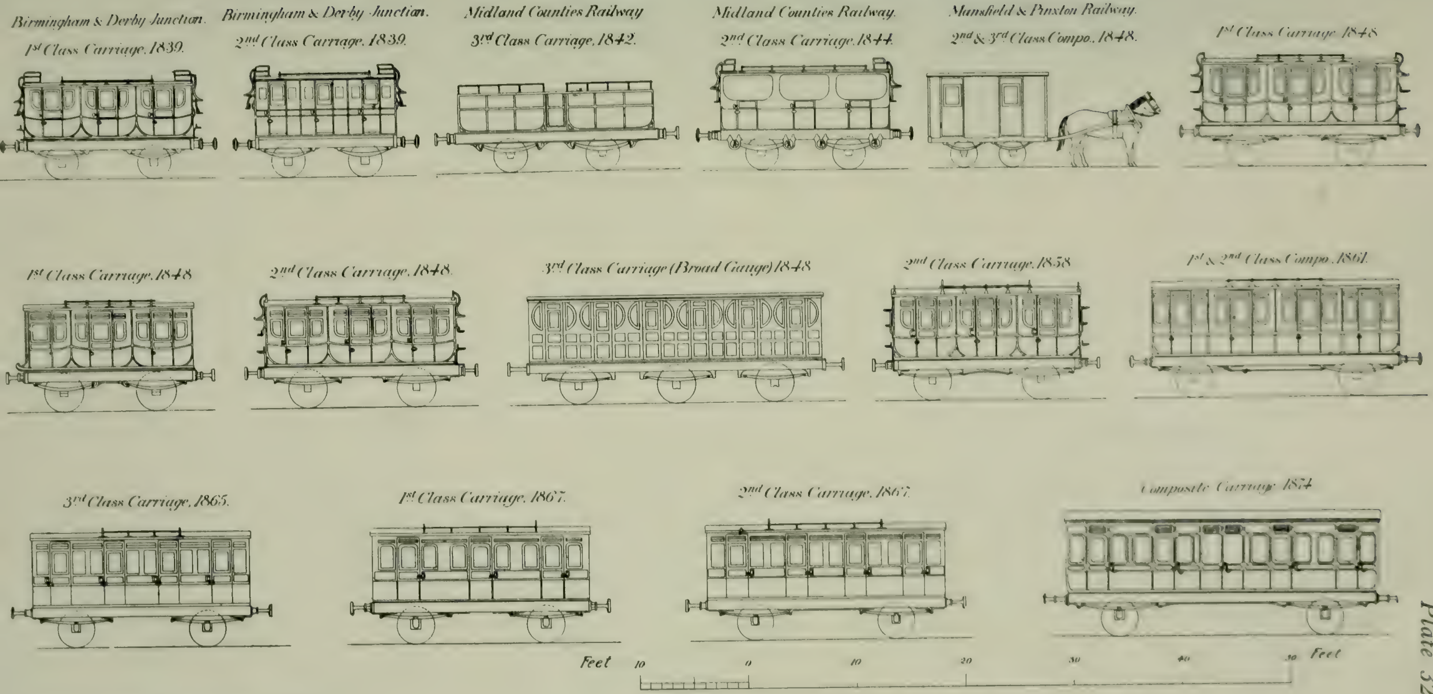
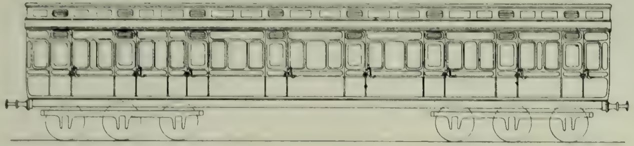

Birmingham & Derby Junction. 1st Class Carriage, 1839.
Birmingham & Derby Junction. 2nd Class Carriage, 1839.
Midland Counties Railway 3rd Class Carriage, 1842.
Midland Counties Railway. 2nd Class Carriage, 1844.
Mansfield & Pinxton Railway. 2nd & 3rd Class Compo., 1848.
1st Class Carriage 1848
1st Class Carriage, 1848
2nd Class Carriage, 1848.
3rd Class Carriage (Broad Gauge) 1848
2nd Class Carriage, 1858
1st & 2nd Class Compo. 1861.
3rd Class Carriage, 1865.
1st Class Carriage, 1867.
2nd Class Carriage, 1867.
Composite Carriage 1874
Feet
10
0
10
20
30
40
50
Feet

Plate 32.

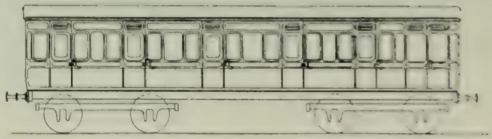
PRESIDENT'S ADDRESS.

Midland Passenger Vehicles, 1875 to 1897.

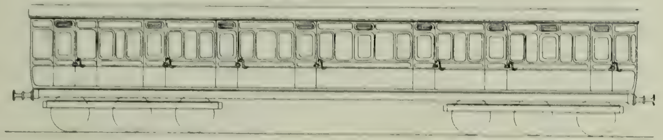
Bogie Composite Carriage, 1875.



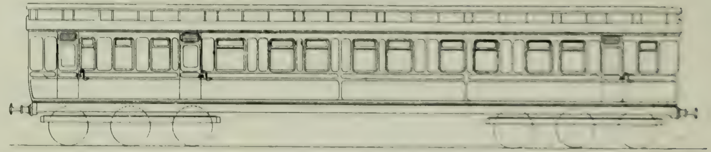
Bogie Composite Carriage, 1877.



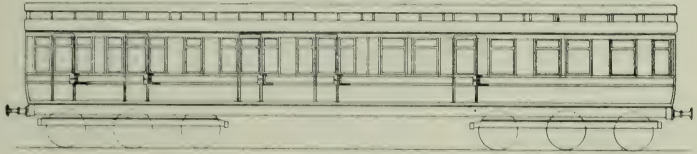
Bogie Composite Carriage, 1889
(Grand Prix, Paris)



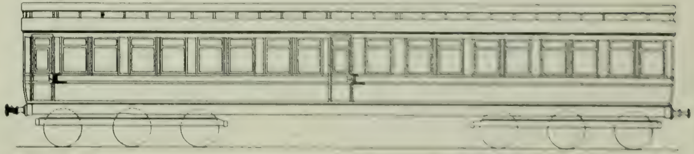
1st Class Dining Carriage, 1896



Composite 1st Class Dining Carriage, 1897.



3rd Class Dining Carriage, 1897.



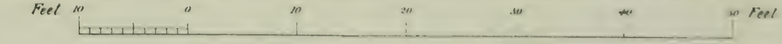
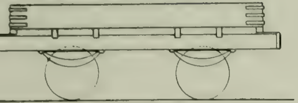


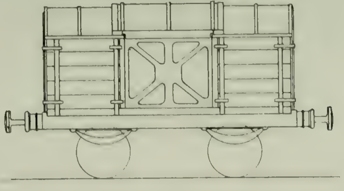
Plate 33.

Midland Goods Wagons, 1844 to 1897.

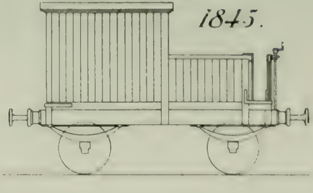
*Low-sided
Goods Wagon.
1844.*



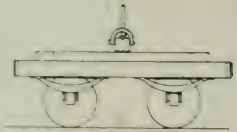
Goods Wagon. 1848.



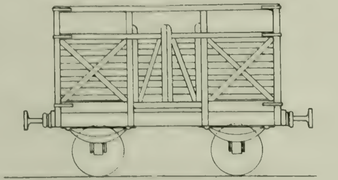
*Brake Wagon.
1845.*



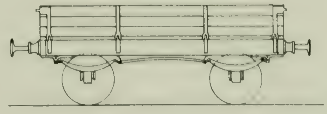
*Timber Wagon
1850.*



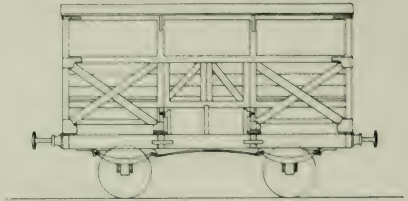
Cattle Wagon, 1851.



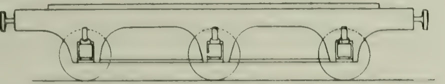
*Low-sided Goods Wagon.
1858.*



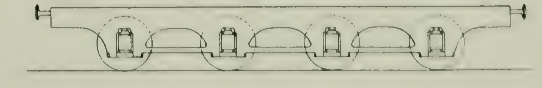
Covered Cattle Wagon. 1861.



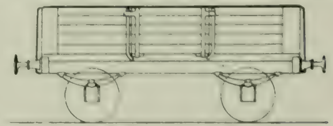
20-Ton Boiler Truck. 1861.

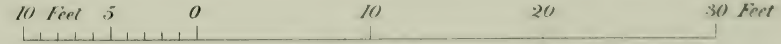


40-Ton Boiler Truck. 1864.

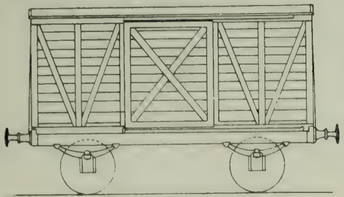


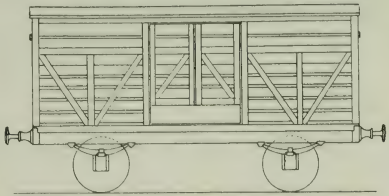
8-Ton High-sided Wagon. 1897.

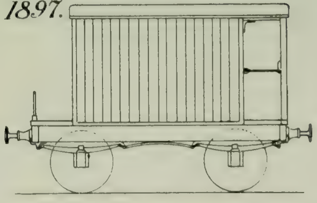


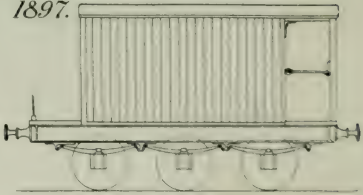


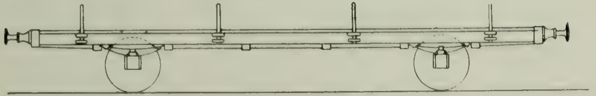
Midland Goods Wagons, 1882 to 1897.

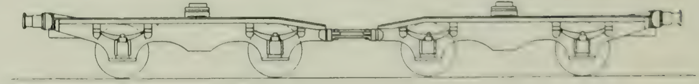

Covered Goods Wagon, 1897.

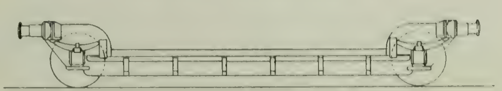

Long Cattle Wagon, 1897.

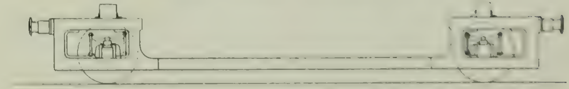

10-Ton Goods Brake Van, 1897.

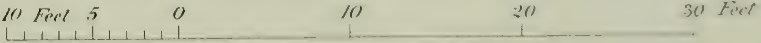

20-Ton Goods Brake Van, 1897.


12-Ton Case Wagon, 1890.


Twin Boiler Truck to carry 30 Tons, 1889.

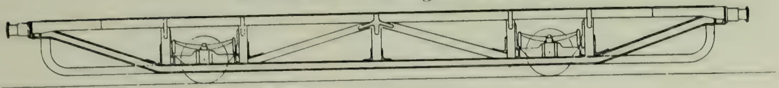

15-Ton Truck, 1884.


18-Ton Boiler Truck, 1882.

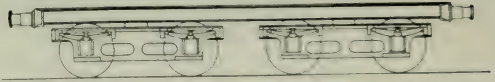


Midland Goods Wagons, 1881 to 1897.

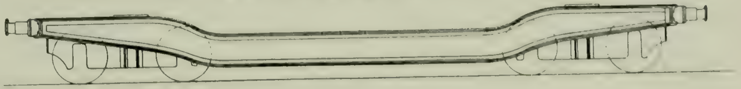
40-foot Case Wagon, 1881.



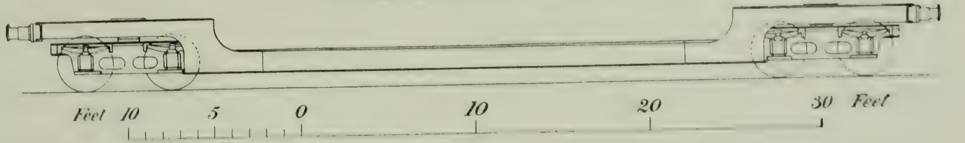
40-Ton Armour Plate Truck, 1889.



50-Ton Truck, 1884



30-Ton Boiler Truck, 1897.



Express Dining Train, Midland Railway.

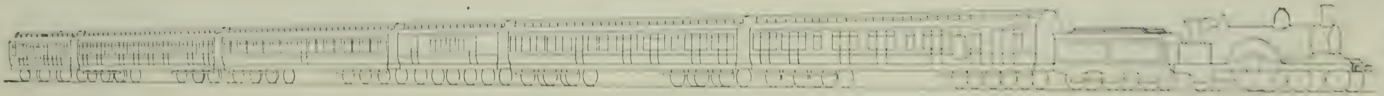
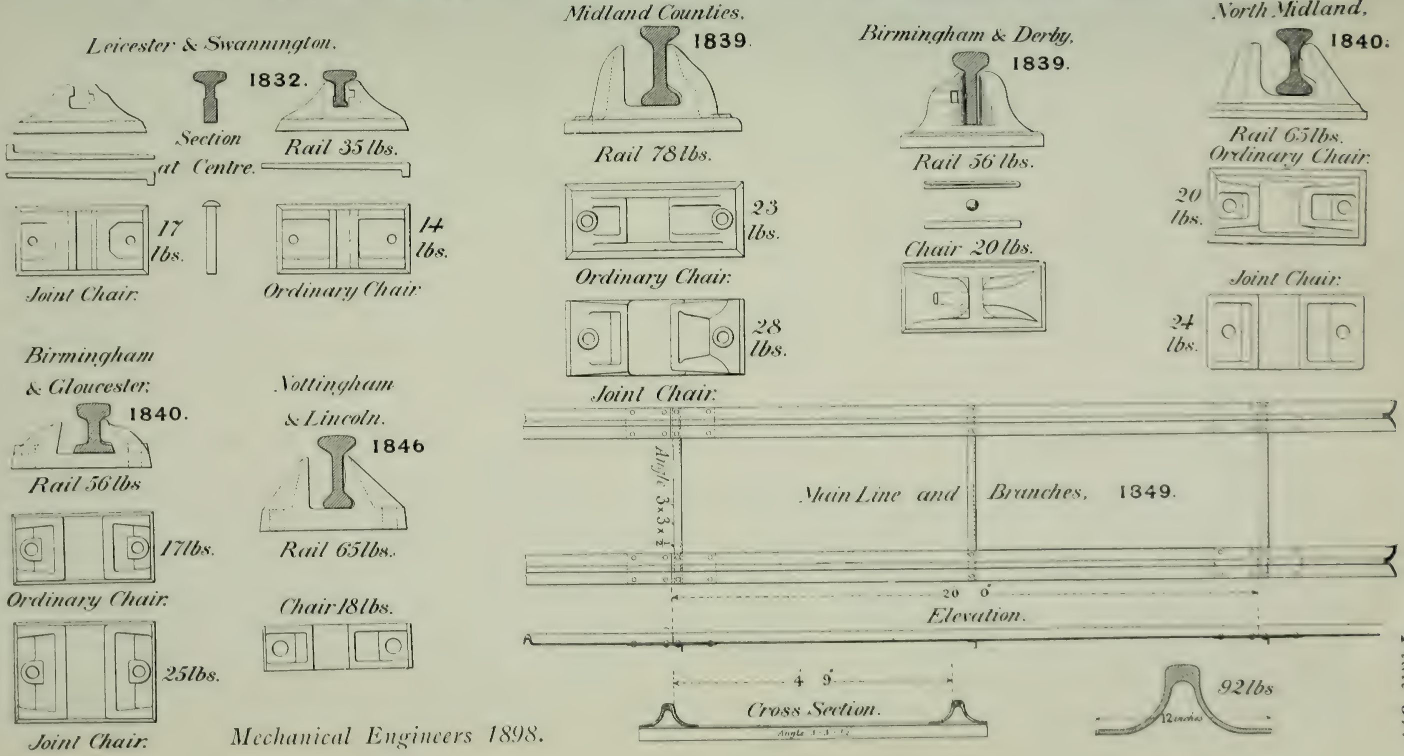


Plate 36.

Midland Railway. Rails and Chairs used from 1832 to 1849.

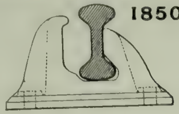


PRESIDENT'S ADDRESS.

Midland Railway, Rails and Chairs used from 1850 to 1897

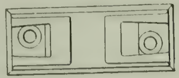
M.R. Main Line & Branches,

1850.



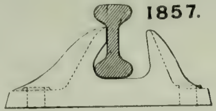
Rail 80lbs.

Chair 28lbs.



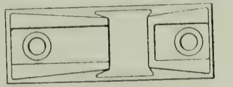
Leicester & Hitchin.

1857.



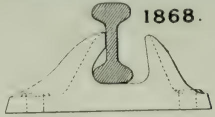
Rail 80lbs.

Chair 34lbs.



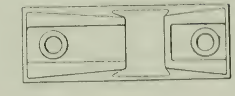
Bedford & London.

1868.



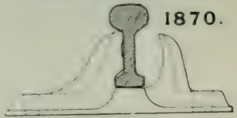
Rail 83lbs.

Chair 34lbs.



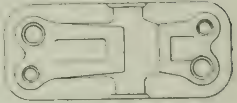
Settle & Carlisle.

1870.



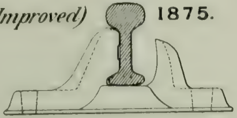
Rail 81 lbs.

Chair 40lbs.



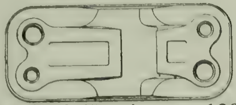
Settle & Carlisle,

(Improved) **1875.**



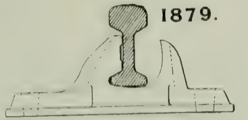
Rail 83lbs.

Chair 40lbs.



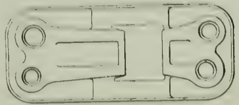
M.R. Inside Key.

1879.



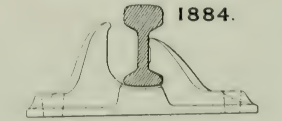
Rail 85lbs.

Chair 40lbs.



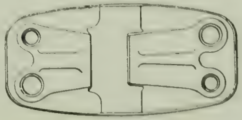
M.R. Outside Key.

1884.



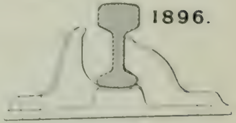
Rail 85lbs.

Chair 50lbs.



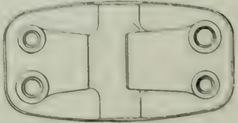
M.R. Outside Key.

1896.



Rail 100lbs.

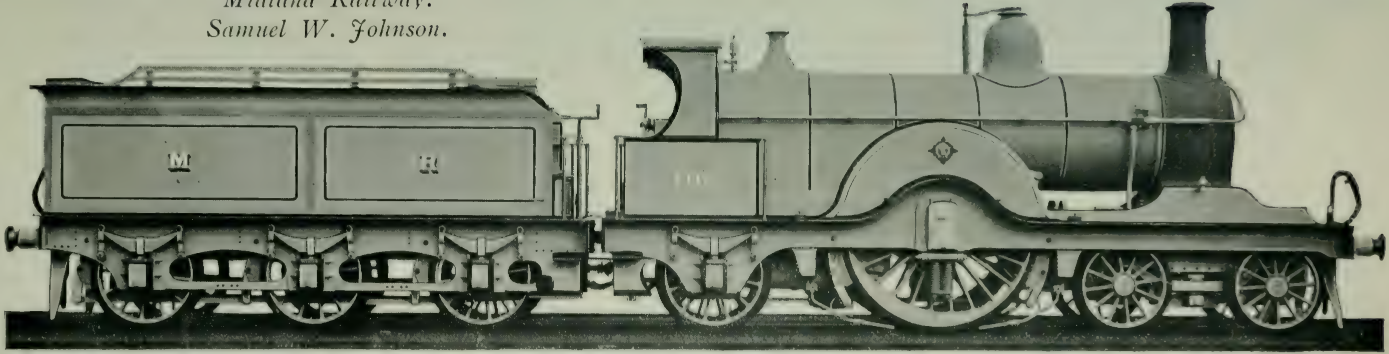
Chair 54lbs.



Mechanical Engineers 1898.

Plate 38.

Midland Railway.
Samuel W. Johnson.



Midland Railway.
Samuel W. Johnson.

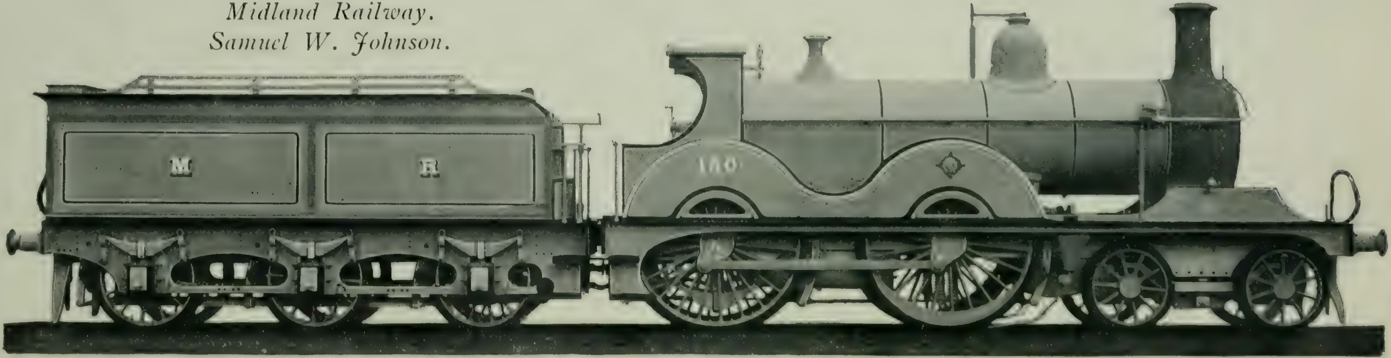
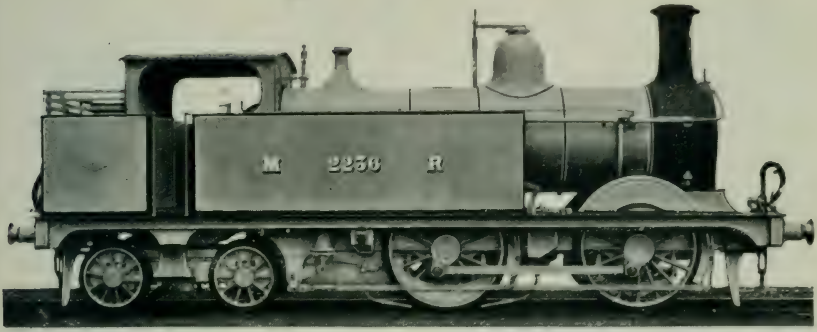
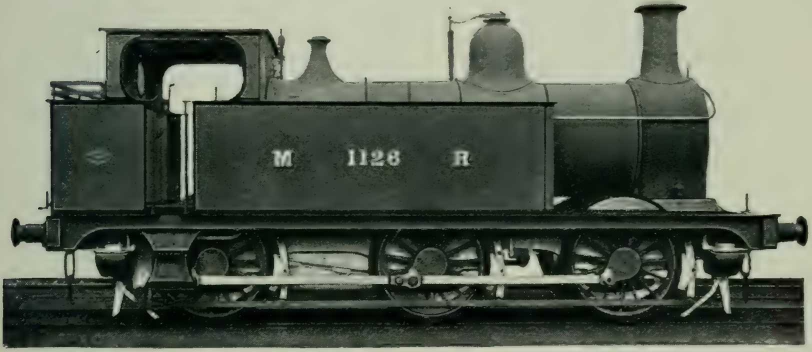
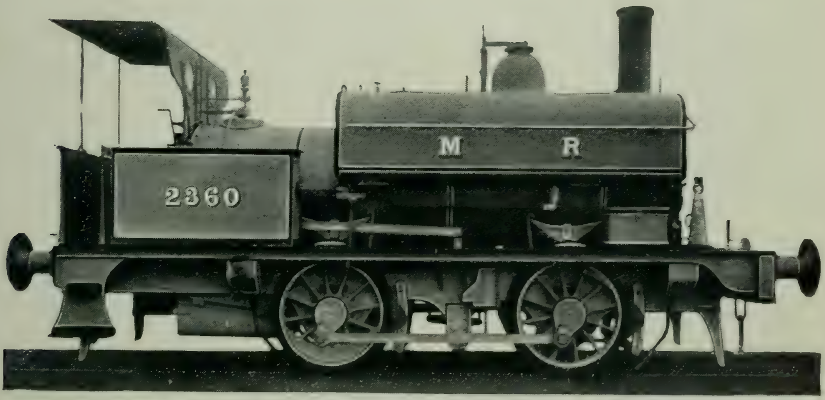


Plate 39.

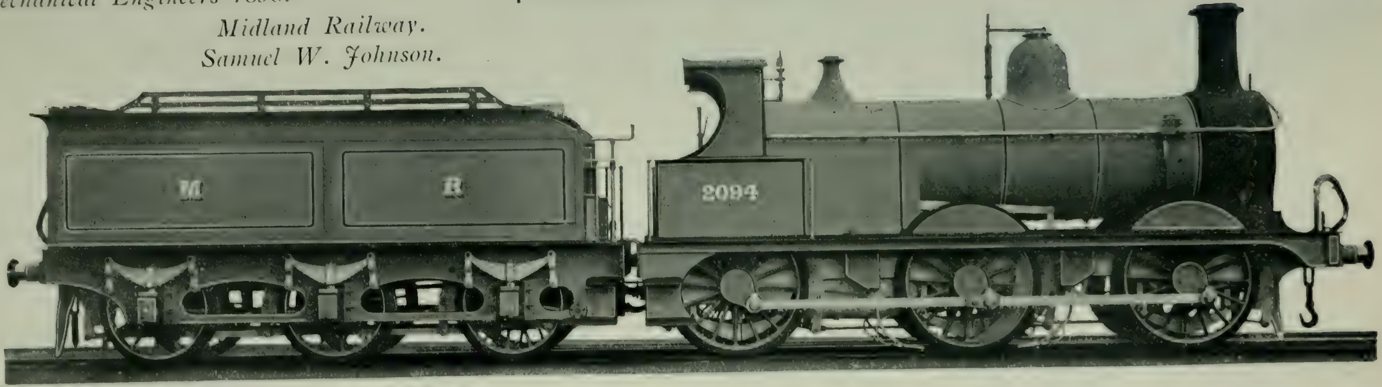
Midland Railway.
Samuel W. Johnson.







Midland Railway.
Samuel W. Johnson.



1897-8. Caledonian Railway.
John F. McIntosh.

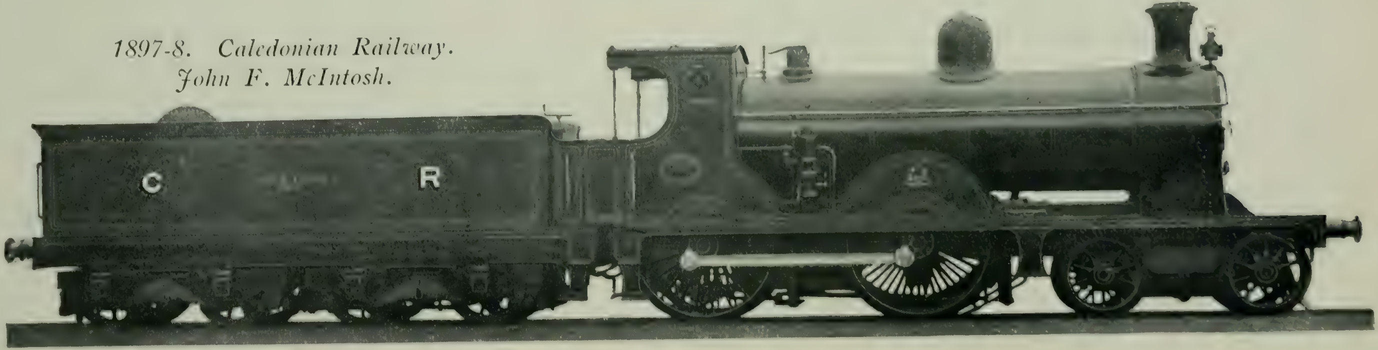
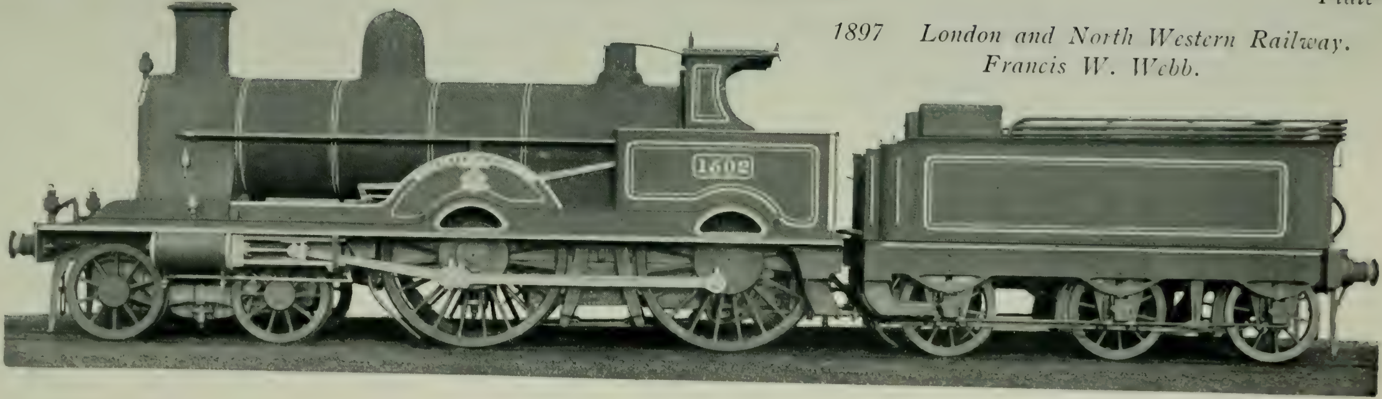
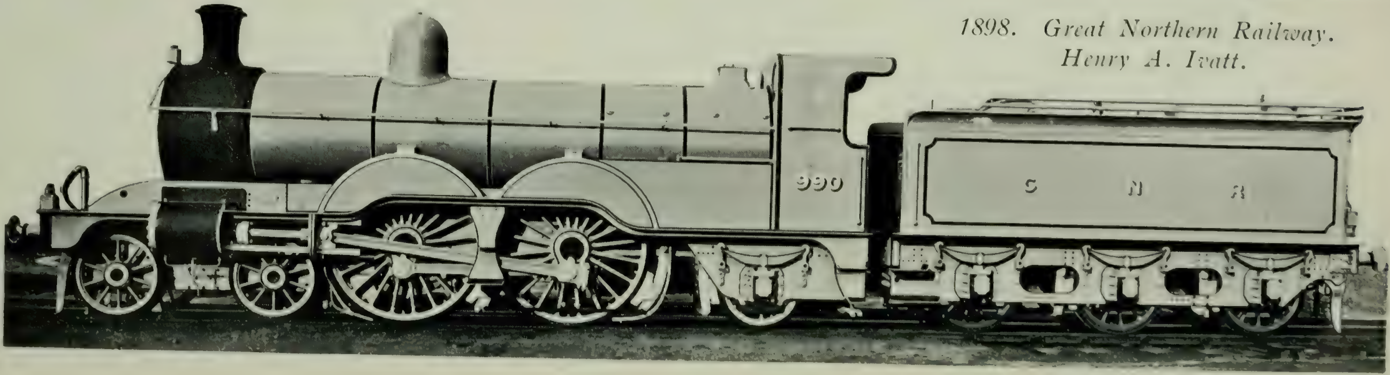


Plate 41.



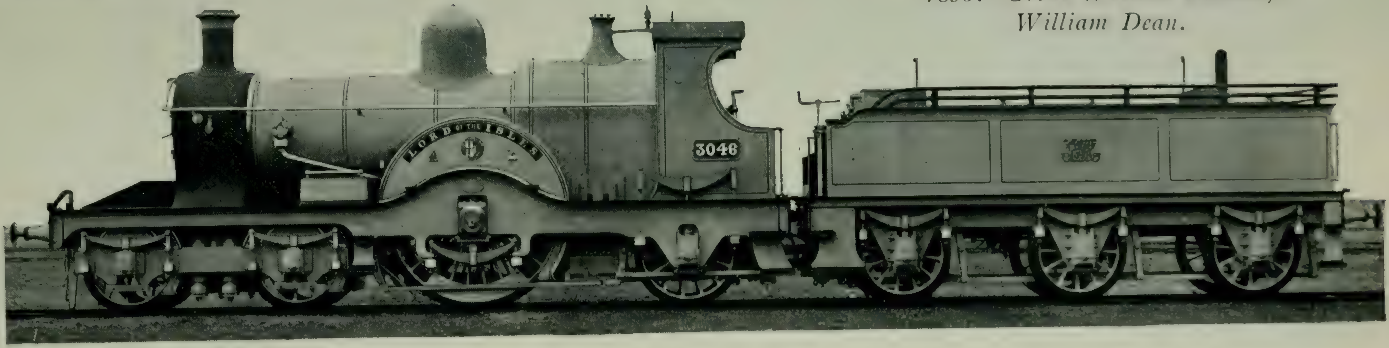
1897 London and North Western Railway.
Francis W. Webb.



1898. Great Northern Railway.
Henry A. Ivatt.

Plate 42.

1895. Great Western Railway.
William Dean.



1896. North Eastern Railway.
Wilson Worsdell.

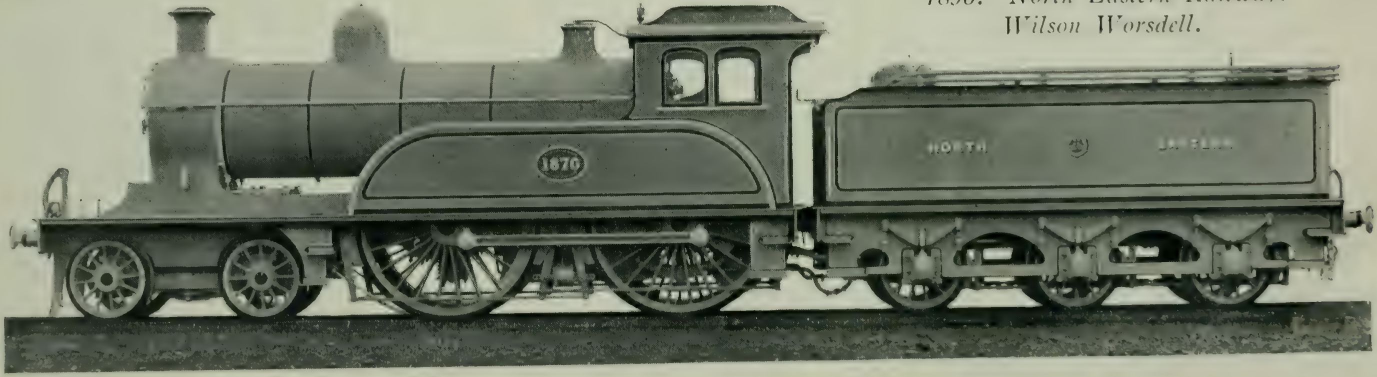
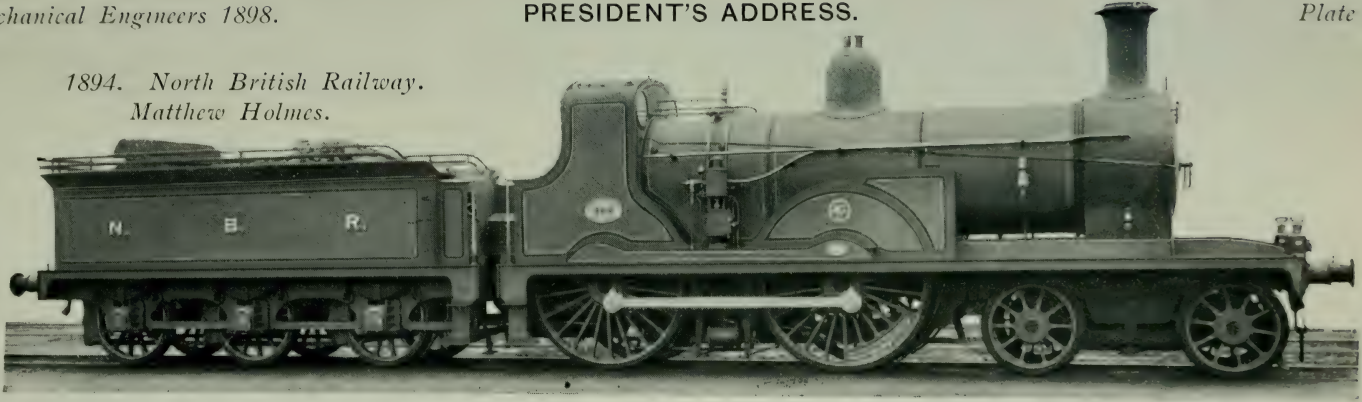
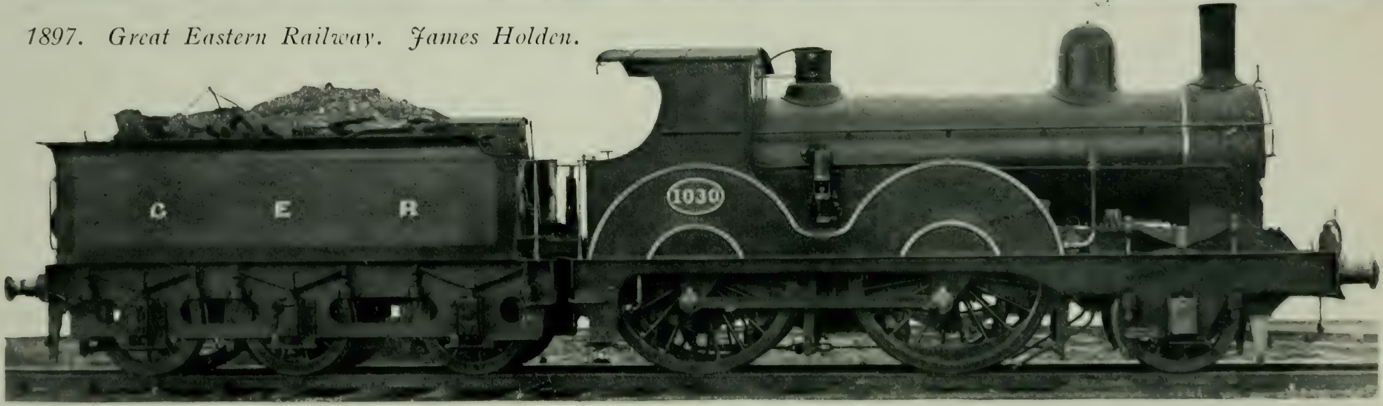


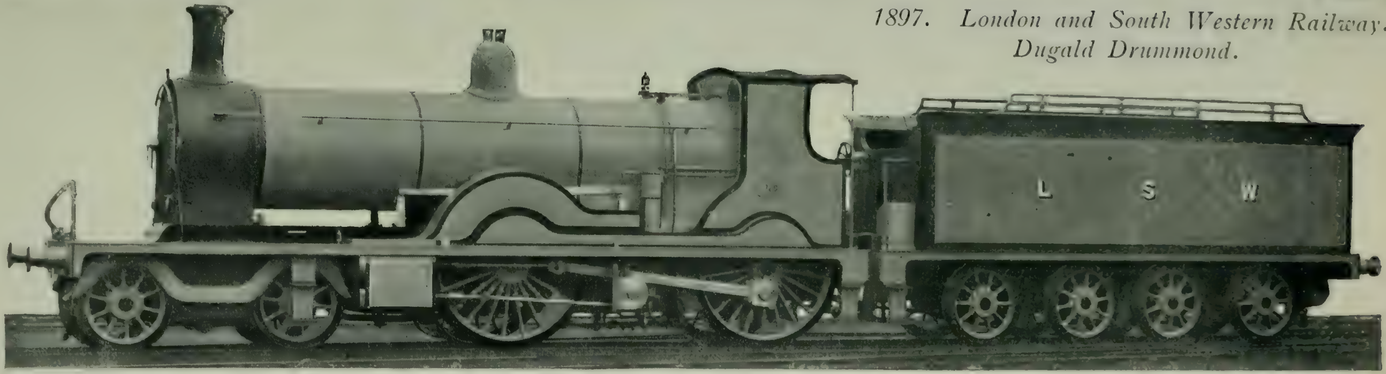
Plate 43.

1894. North British Railway.
Matthew Holmes.

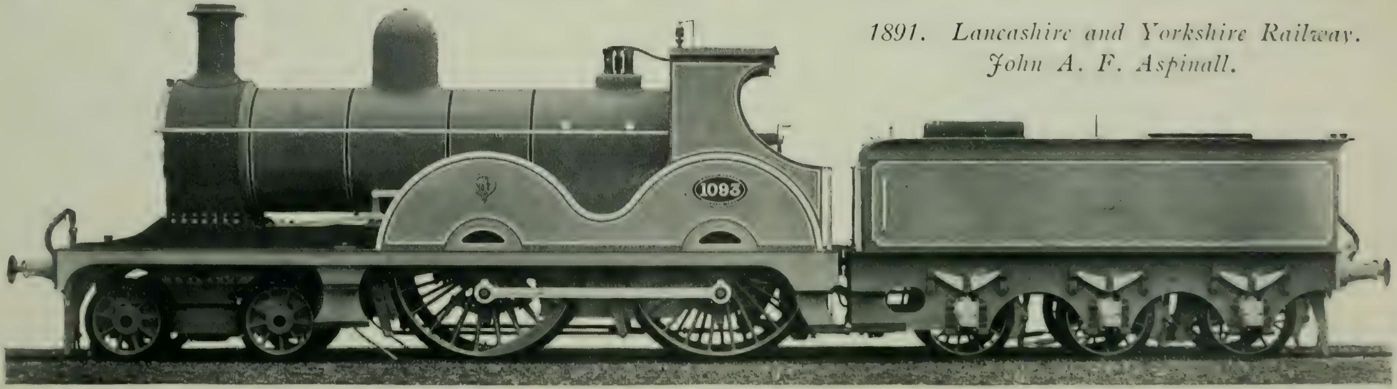


1897. Great Eastern Railway. James Holden.

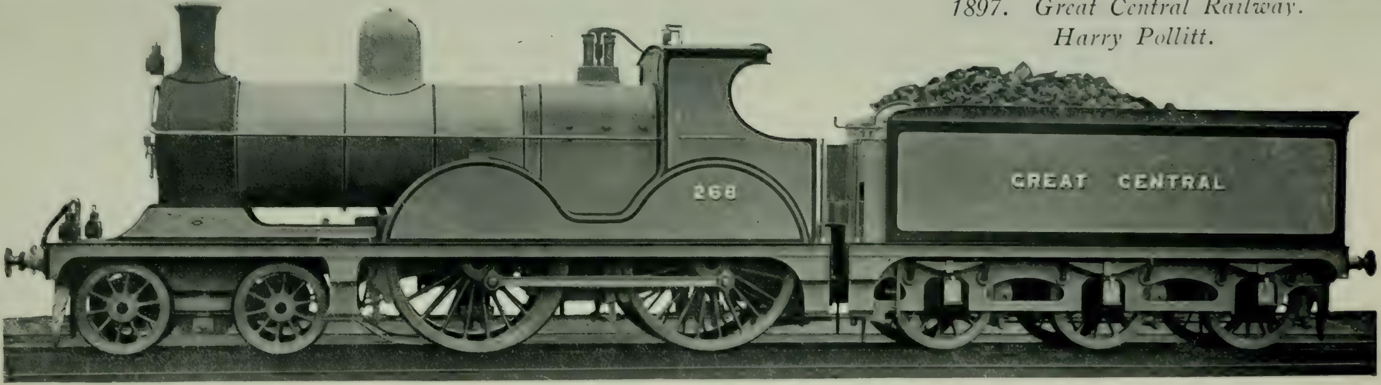




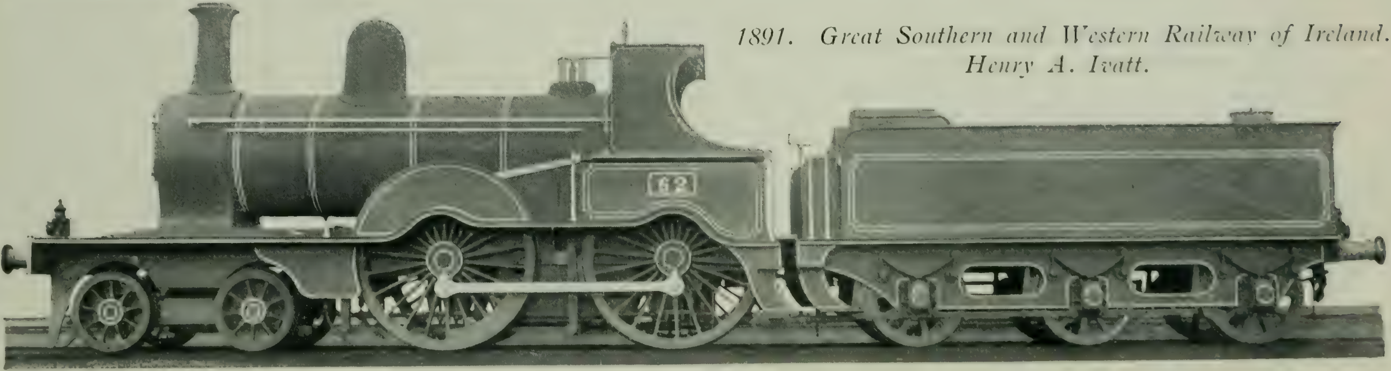
1897. London and South Western Railway.
Dugald Drummond.



1891. Lancashire and Yorkshire Railway.
John A. F. Aspinall.



1897. *Great Central Railway.*
Harry Pollitt.



1891. *Great Southern and Western Railway of Ireland.*
Henry A. Ivatt.

1897. London, Brighton, and South Coast Railway.
Robert J. Billinton.

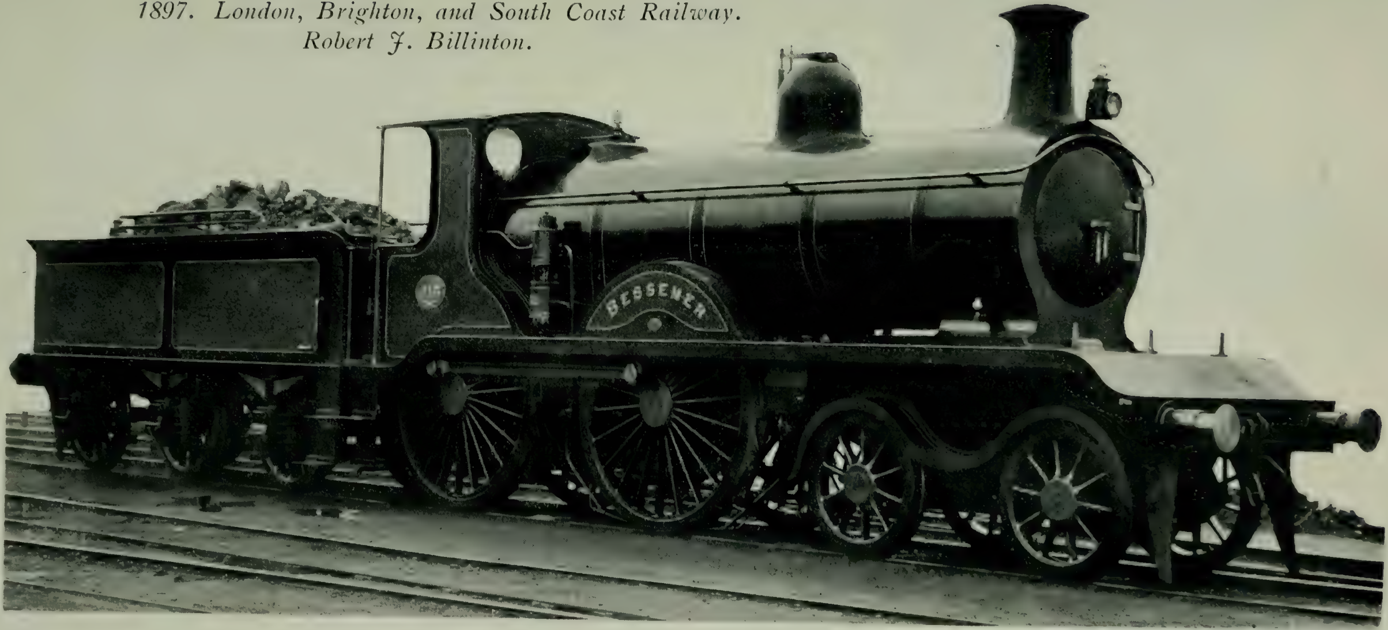
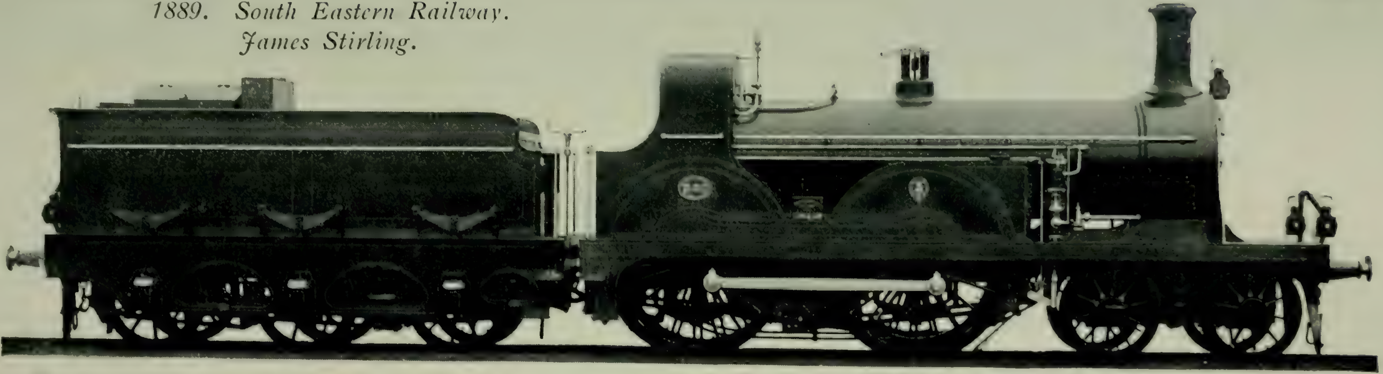


Plate 47.

1889. South Eastern Railway.
James Stirling.



1897. Glasgow and South Western Railway.
James Manson.

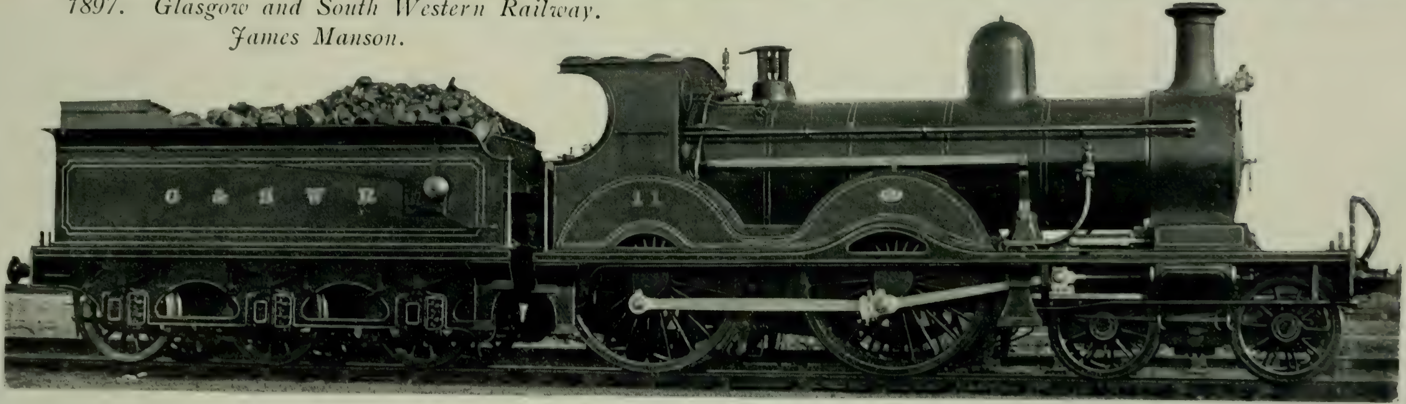


Plate 48.

GAS-ENGINE RESEARCH.

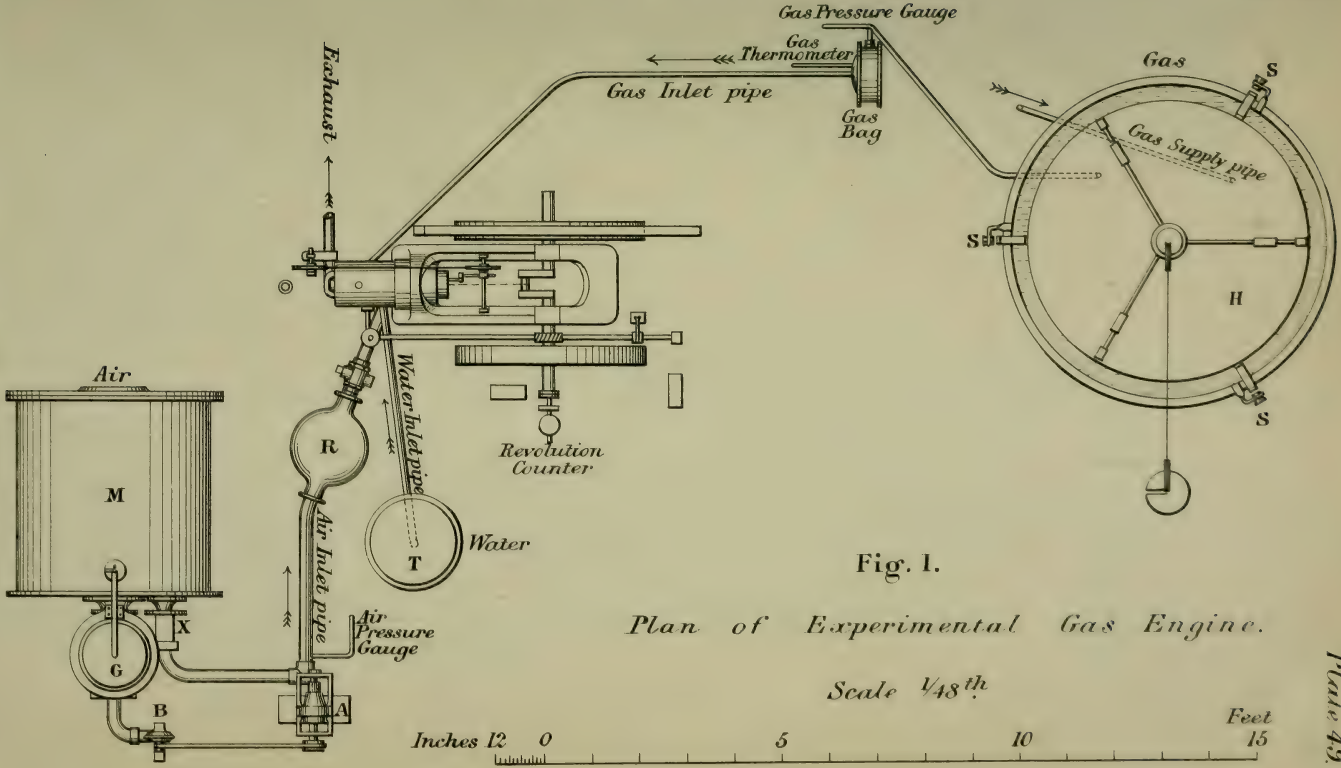


Fig. 1.

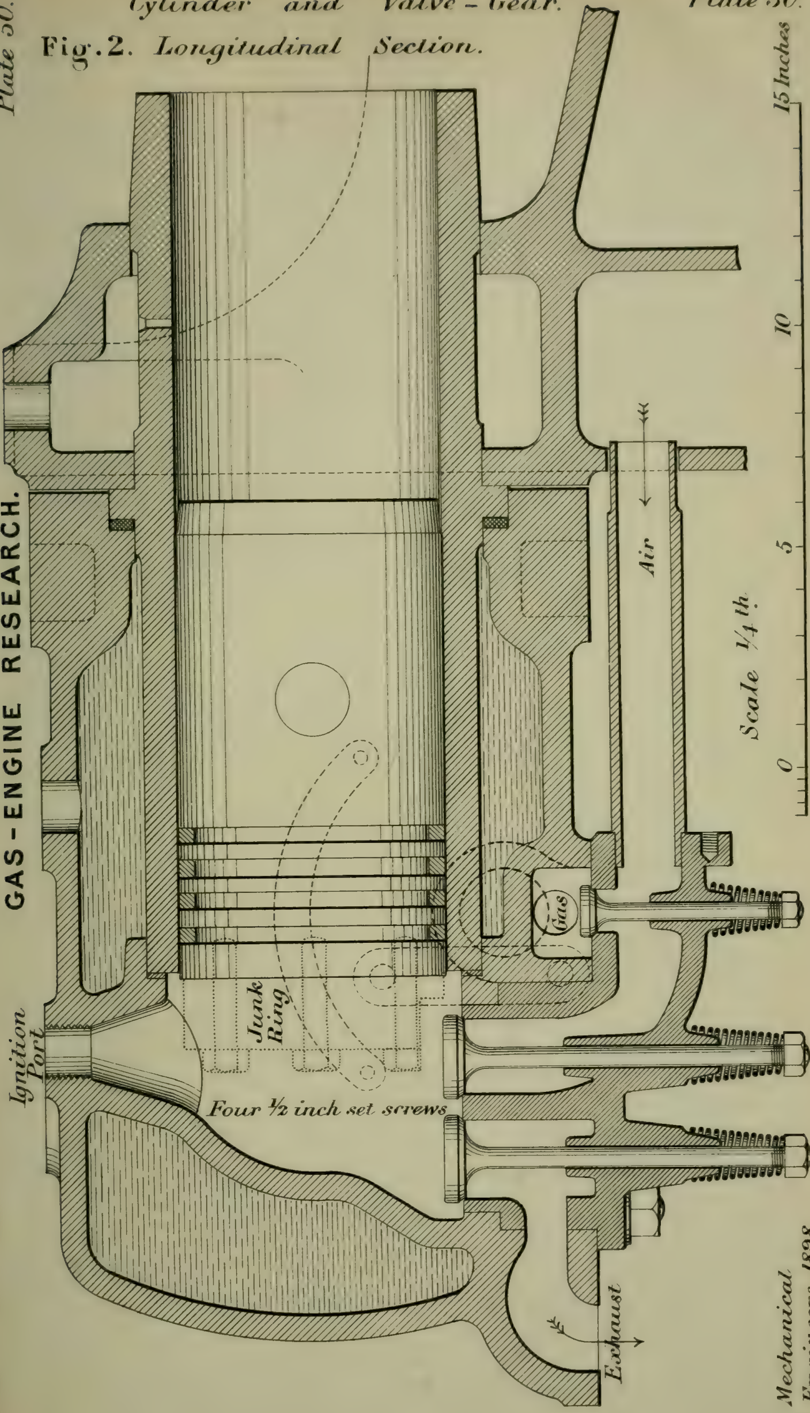
Plan of Experimental Gas Engine.

Scale 1/48th.

GAS-ENGINE RESEARCH.

Cylinder and Valve-Gear.

Fig. 2. Longitudinal Section.



Cylinder and Valve-Gear.

Fig. 3. *Side Elevation.*

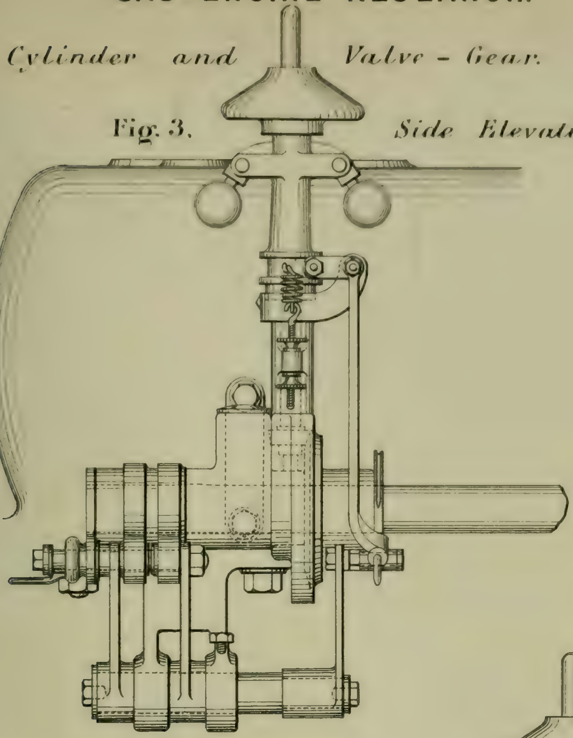
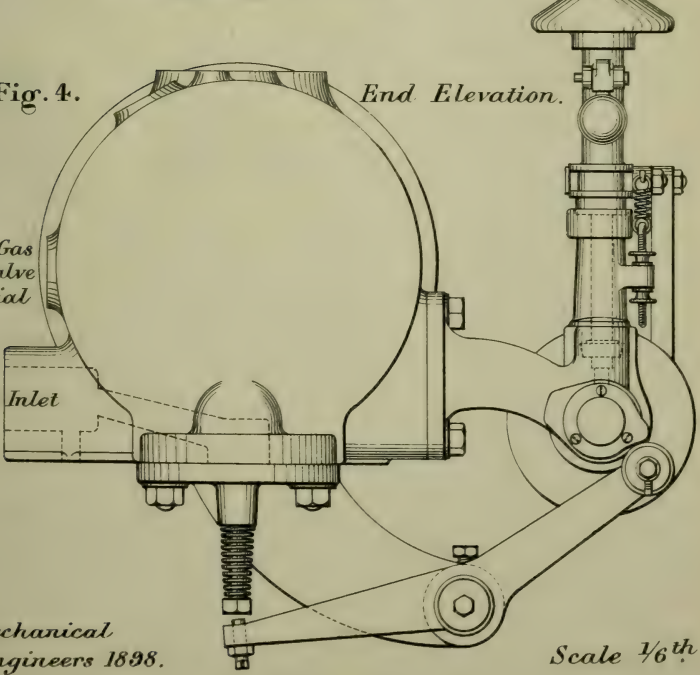


Fig. 4. *End Elevation.*



Mechanical Engineers 1898.

Scale 1/6th.

Cylinder and Valve-Gear.

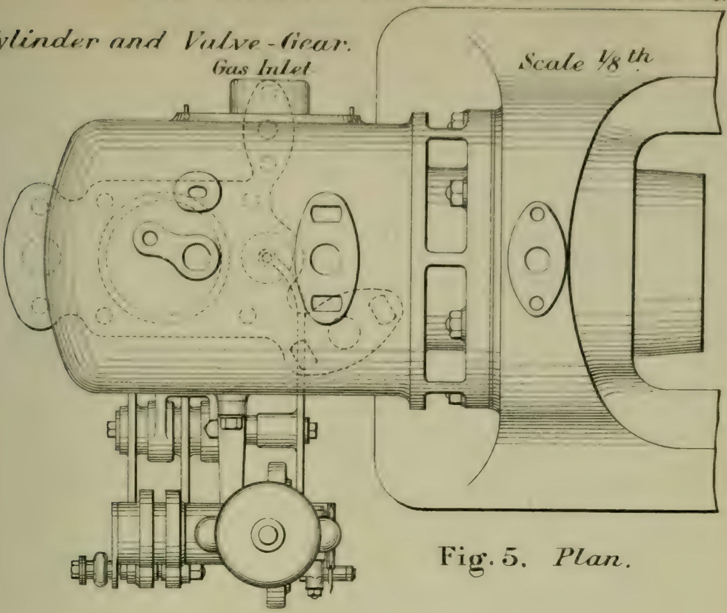


Fig. 5. *Plan.*

Indicator Driving Gear.

Fig. 6. *Plan.*

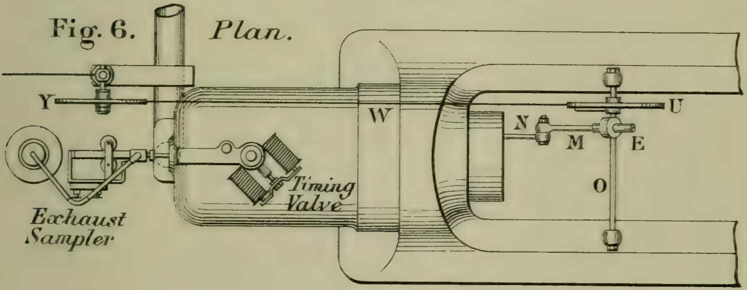
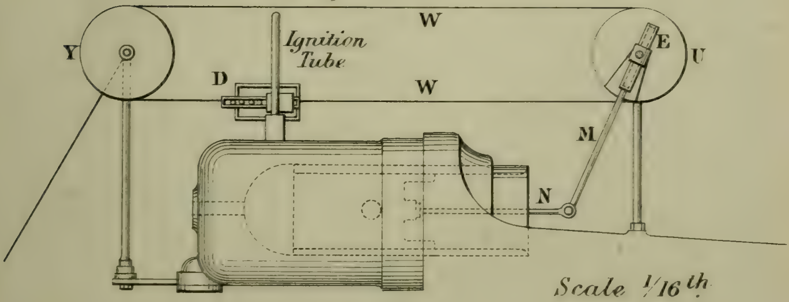


Fig. 7. *Elevation.*



GAS-ENGINE RESEARCH.

Indicator.

Fig. 8. Front Elevation.

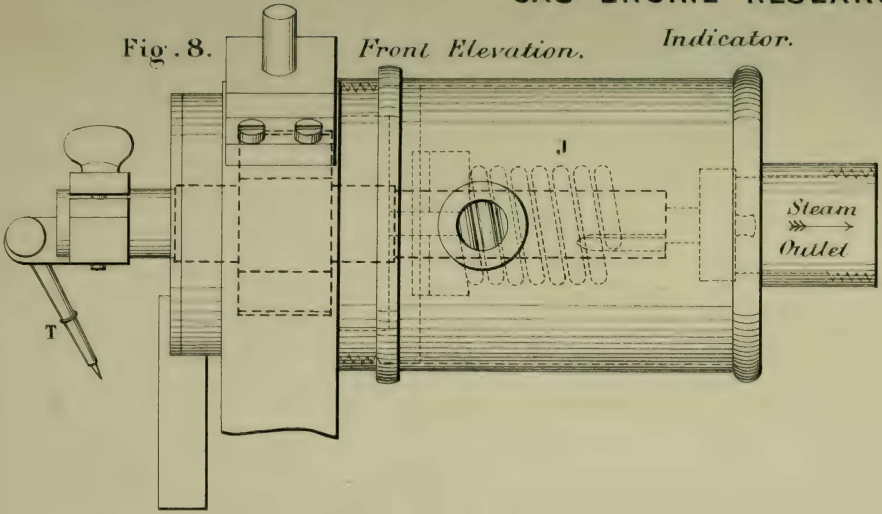
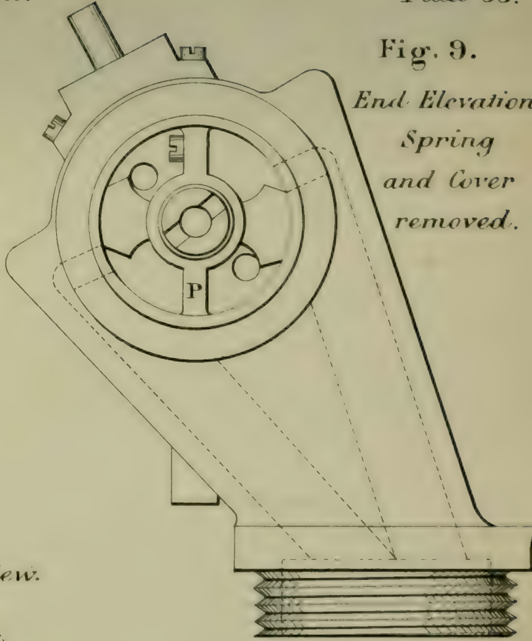


Fig. 9. End Elevation
Spring
and Cover
removed.



Piston.

Fig. 10. Elevation.

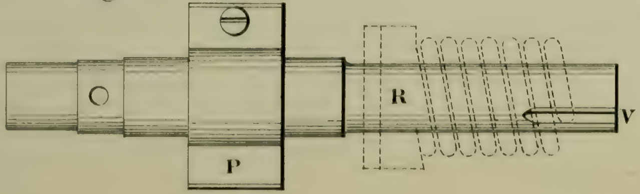
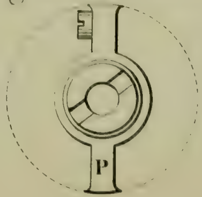


Fig. 11. End view.



Full size.

Mechanical Engineers 1898.

GAS-ENGINE RESEARCH.

Indicator.

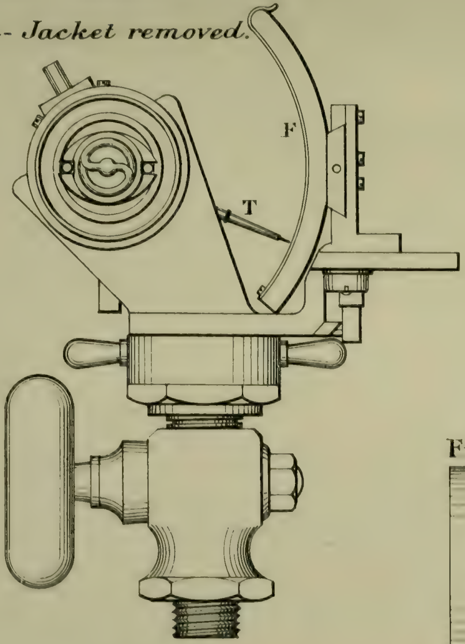


Fig. 12. *End Elevation.*

Steam-Jacket removed.

Half full size.

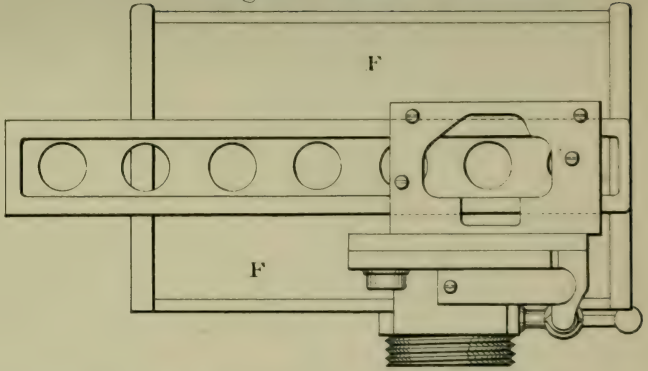


Fig. 13. *Back Elevation.*

Front Cover of Indicator.

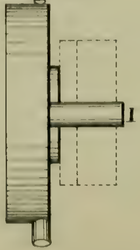


Fig. 14.

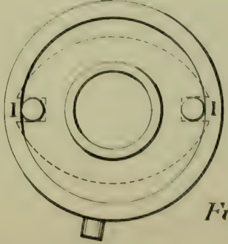


Fig. 15.

Spring.

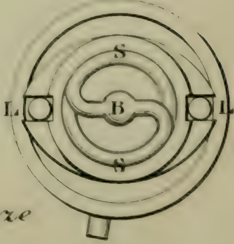


Fig. 16.

Full size

Mechanical Engineers 1898.

Exhaust Sampler.

Fig. 17. *Plan.*

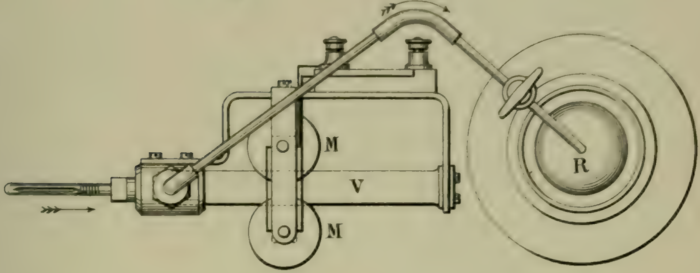
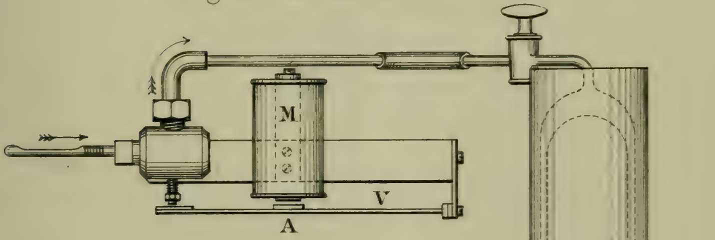
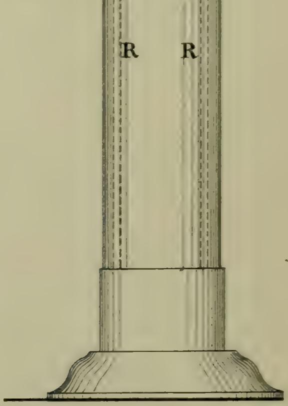


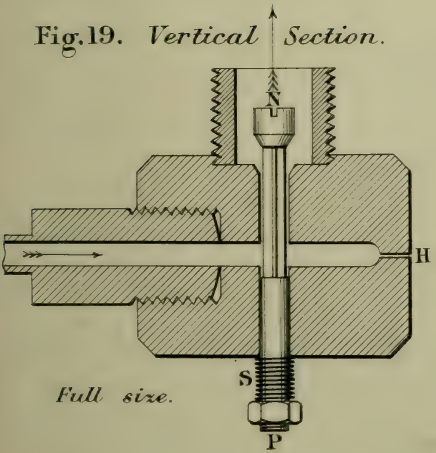
Fig. 18. *Elevation.*



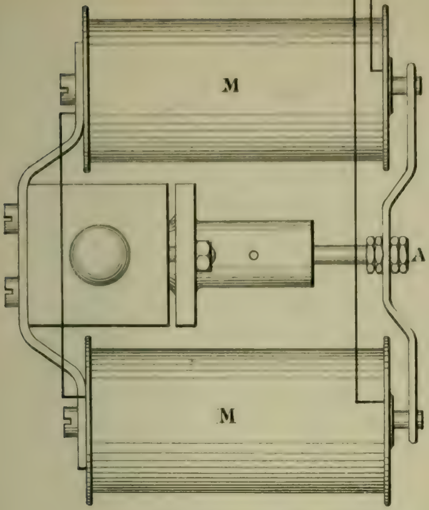


Scale 1/4th.

Fig. 19. *Vertical Section.*



Full size.



Timing Valve.

Fig. 20.

Plan, Valve Open.

Half full size.

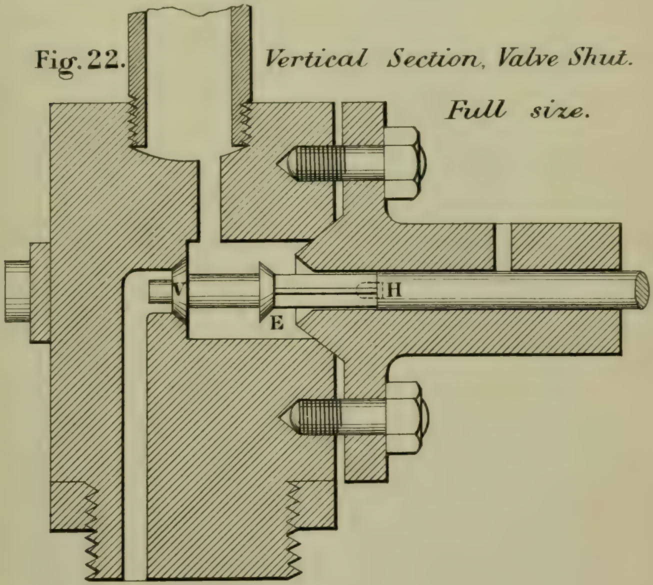


Fig. 22. *Vertical Section, Valve Shut.*

Full size.

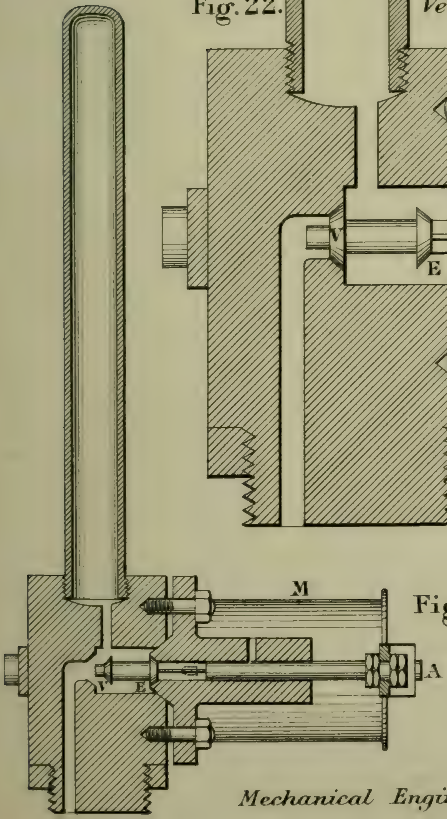


Fig. 21. *Sectional Elevation, Valve Open.*

Half full size.

Contact Breaker for Timing Valve.

Fig. 23. *Plan.*

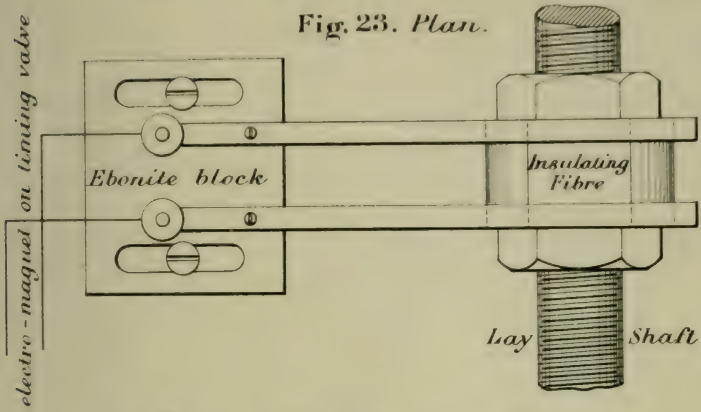
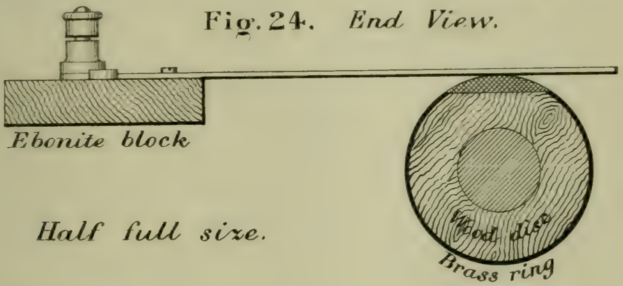


Fig. 24. *End View.*



Half full size.

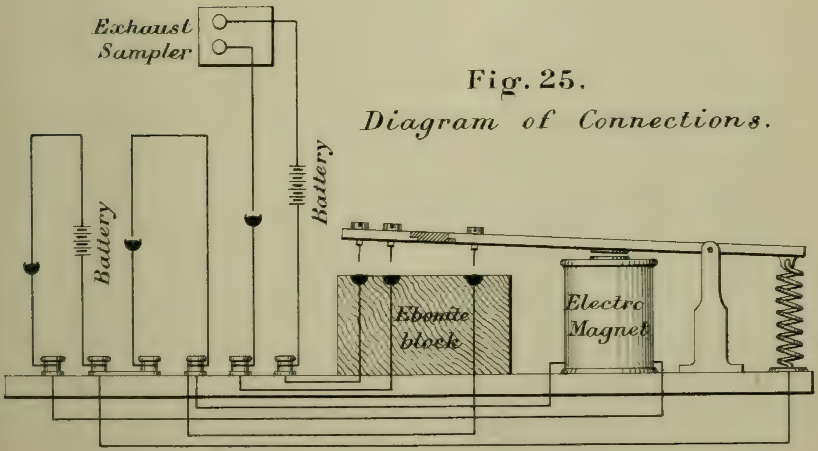
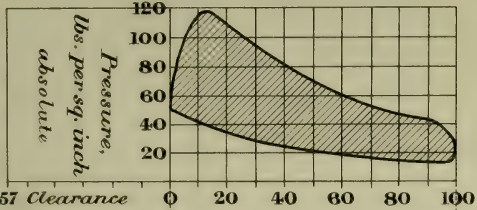


Fig. 25.
Diagram of Connections.

GAS-ENGINE RESEARCH.

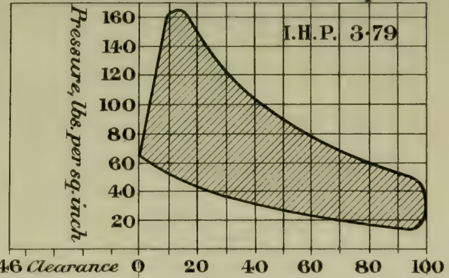
Test 1.

Area 14·40 *square inches*
Mean Pressure 47·65 *lbs. per sq. inch*
I.H.P. 1·72



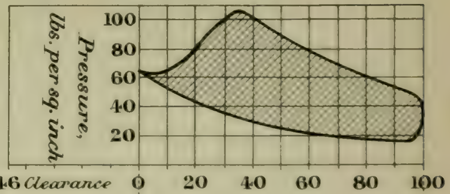
Test 5.

Area 19·53 *square inches*
Mean Pressure 64·65 *lbs. per sq. inch*
I.H.P. 3·79



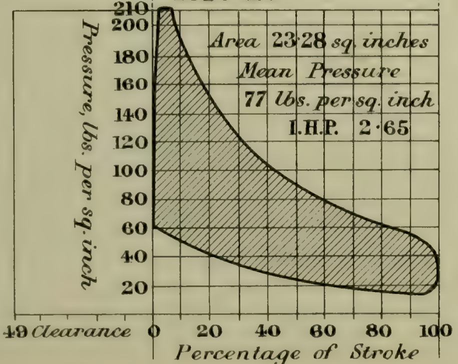
Test 6.

Area 13·78 *square inches*
Mean Pressure 44·58 *lbs. per sq. inch*
I.H.P. 3·41



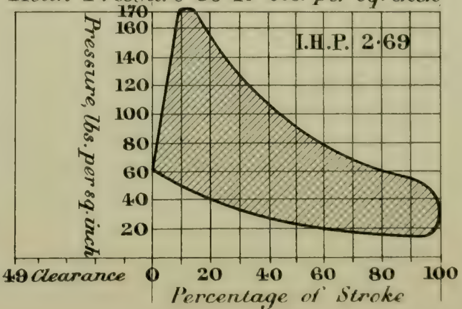
Test 2.

Area 23·28 *sq. inches*
Mean Pressure
77 *lbs. per sq. inch*
I.H.P. 2·65



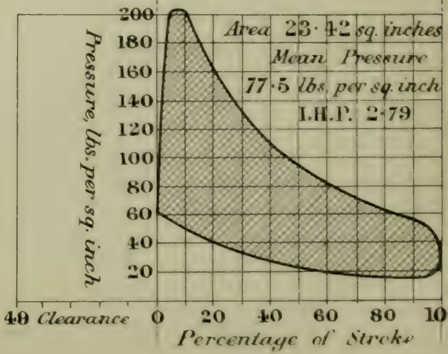
Test 3.

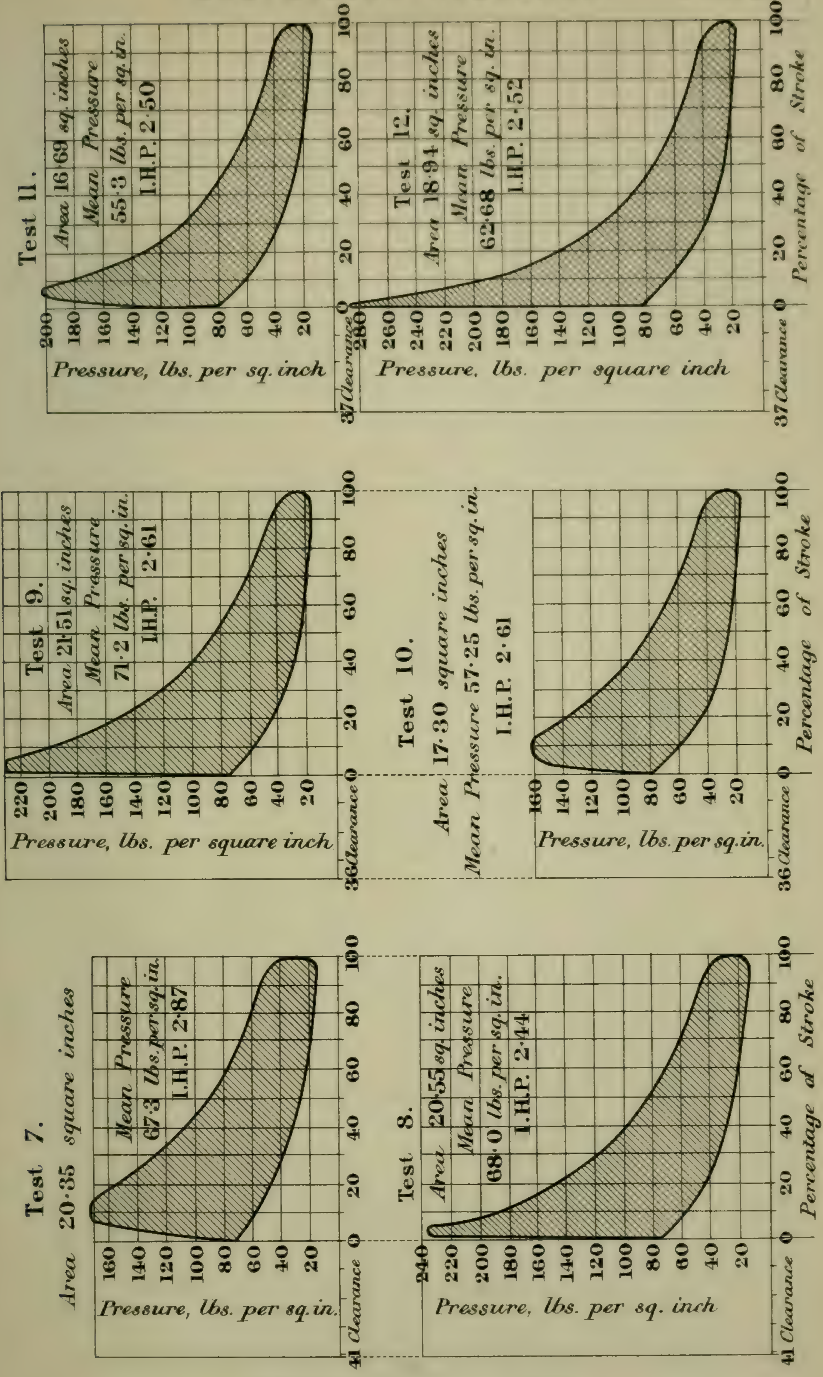
Area 20·99 *square inches*
Mean Pressure 69·47 *lbs. per sq. inch*
I.H.P. 2·69

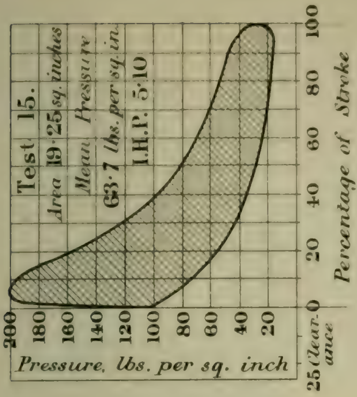


Test 4.

Area 23·42 *sq. inches*
Mean Pressure
77·5 *lbs. per sq. inch*
I.H.P. 2·79




Test 11.
Area 16·69 sq. inches
Mean Pressure
55·3 lbs. per sq. in.
I.H.P. 2·50
Pressure, lbs. per sq. inch
Test 12.
Area 18·94 sq. inches
Mean Pressure
62·68 lbs. per sq. in.
I.H.P. 2·52
Pressure, lbs. per square inch
Test 9.
Area 21·51 sq. inches
Mean Pressure
71·2 lbs. per sq. in.
I.H.P. 2·61
Pressure, lbs. per square inch
Test 10.
Area 17·30 square inches
Mean Pressure 57·25 lbs. per sq. in.
I.H.P. 2·61
Pressure, lbs. per sq. in.
Test 7.
Area 20·35 square inches
Mean Pressure
67·3 lbs. per sq. in.
I.H.P. 2·87
Pressure, lbs. per sq. in.
Test 8.
Area 20·55 sq. inches
Mean Pressure
68·0 lbs. per sq. in.
I.H.P. 2·44
Pressure, lbs. per sq. inch
Percentage of Stroke
Clearance
37
36
41
0
20
40
60
80
100



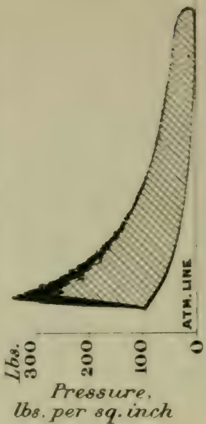
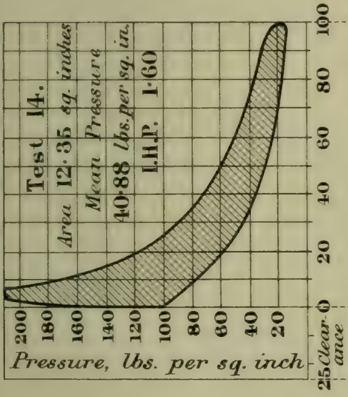
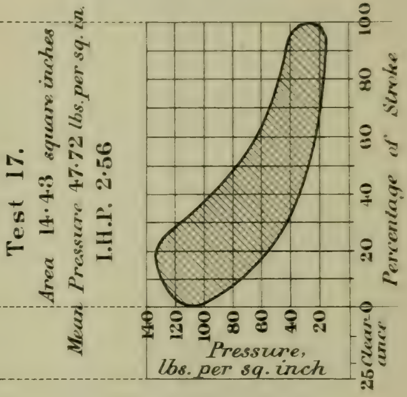
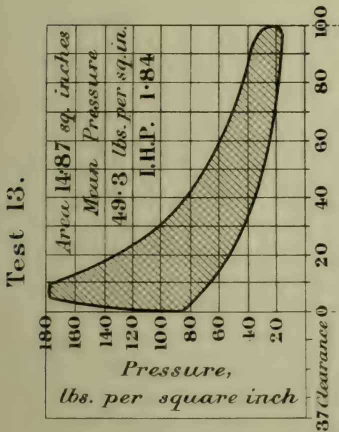


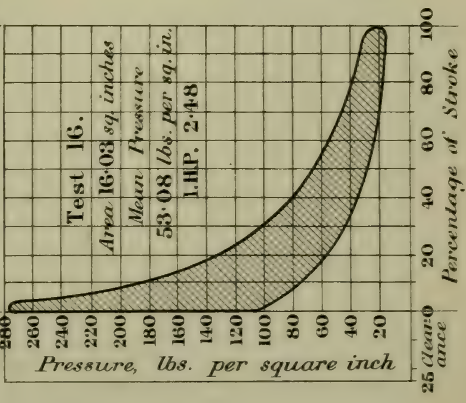
Fig. 26.

Fifty consecutive explosions.
Porcelain ignition-tube.







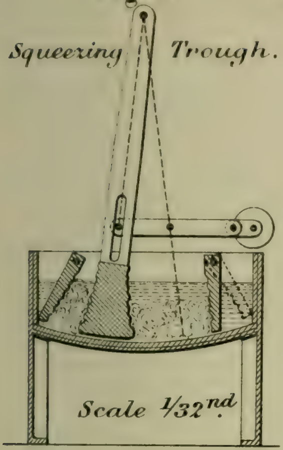


STEAM LAUNDRY MACHINERY. *Plate 61.*

Washing Machines.

Fig. 1.

Squeezing Trough.



Oblique Hexagonal Cage.

Fig. 2.

End view.

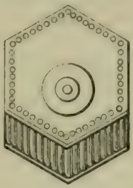
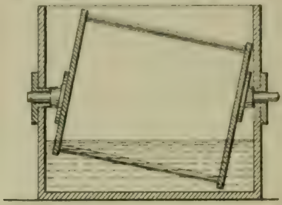


Fig. 3.

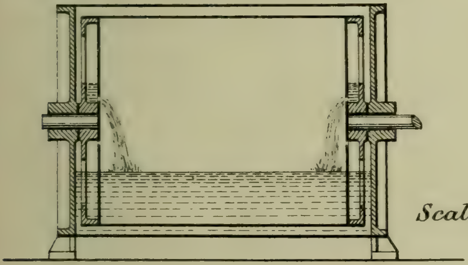
Longitudinal Section.



Scale 1/32nd.

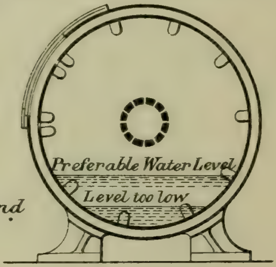
Commonest Washer.

Fig. 4. *Longitudinal Section.*



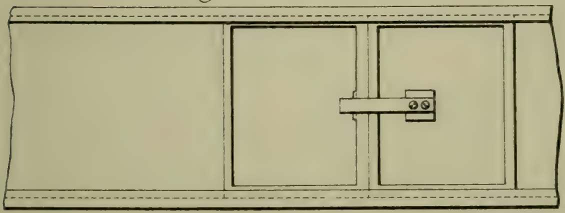
Scale 1/32nd.

Fig. 5. *Transverse Section.*



Sliding Doors.

Fig. 6. *Elevation.*



Transverse Section.

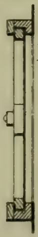
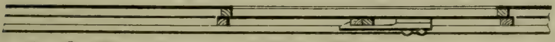


Fig. 7.

Fig. 8. *Plan.*



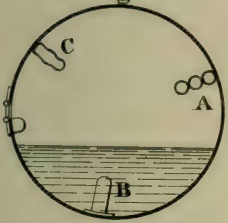
Mechanical Engineers 1898.

Scale 1/16th.

Washing Machines.

Lifters.

Fig. 9.



Scale 1/32nd.

Fig. 10.

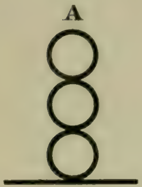


Fig. 11.

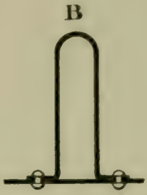
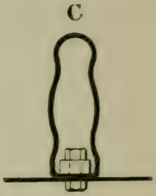


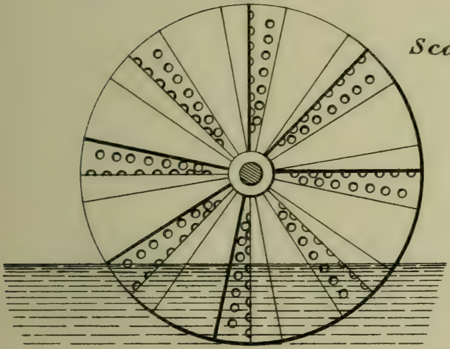
Fig. 12.



Scale 1/8th.

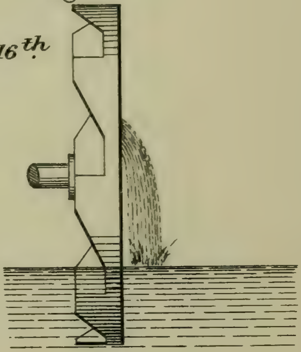
Circulating Action for Cage.

Fig. 13.



Scale 1/16th.

Fig. 14.



Circulating Action for Casing.

Fig. 15.

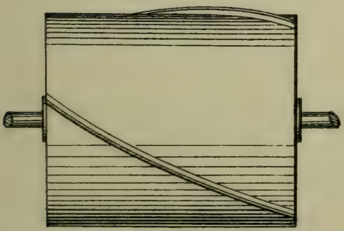
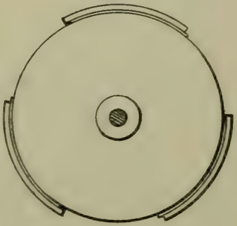


Fig. 16.



Scale 1/32nd.

Washing Machines.

Fig. 17.

Single-Cage Washer.

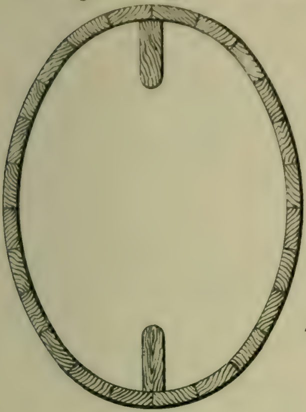
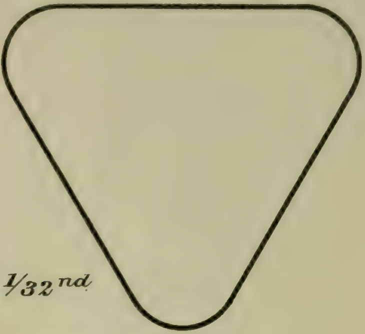


Fig. 18.

Section of German Cage.



Scale 1/32nd

Fig. 19.

Cage in two compartments with two doors.

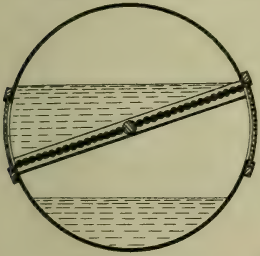
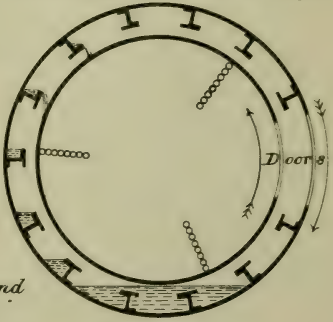


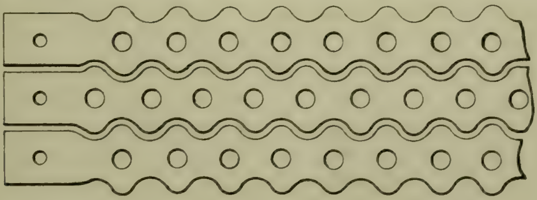
Fig. 20.

Washer with Casing revolving opposite to Cage.



Scale 1/32nd.

Fig. 21. *Brass Bars of Inner Cage. Scale 1/4th.*



STEAM LAUNDRY MACHINERY. *Plate 64.*

Ironing Machines.

Fig. 22. *Ironer with steam roller and rag-made calender.*

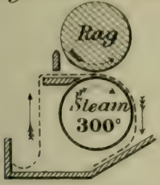


Fig. 23.

Decoudin Ironer.

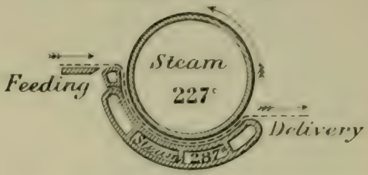


Fig. 24. *Ironer with steam cylinder and three pressing rollers.*

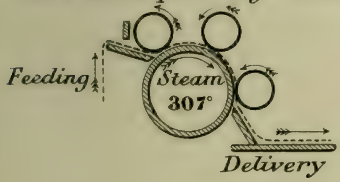


Fig. 25. *Ironer with steam cylinder, five pressing rollers, and one polishing.*

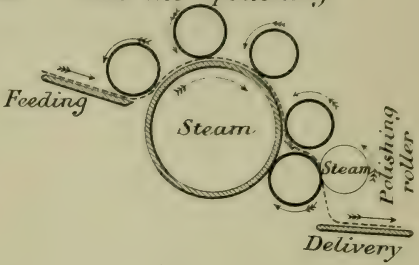


Fig. 26.

Ironer with five pressing rollers and steam beds.

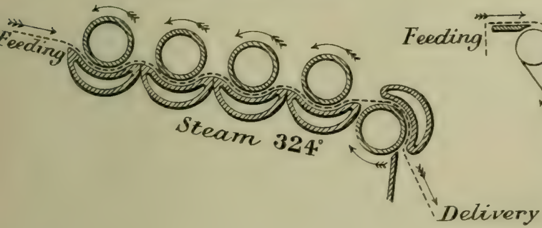


Fig. 27.

Ironer with endless felt band under steam bed.

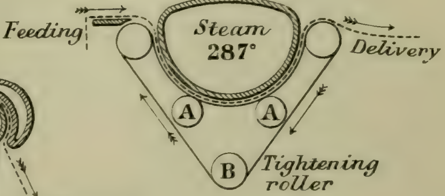
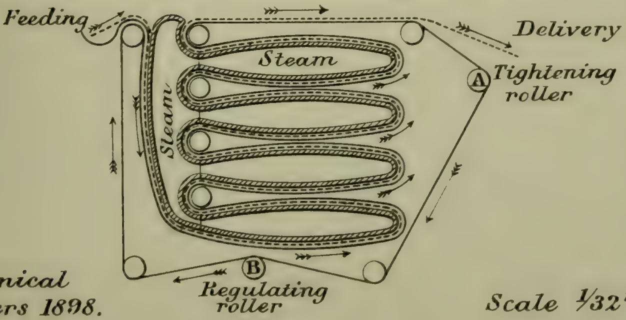


Fig. 28. *Ironer with five steam-chests and cotton-duck band.*



Mechanical Engineers 1898.

Scale 1/32nd.

Ironing Machines.

Fig. 29.

Combination Ironer with two endless bands.

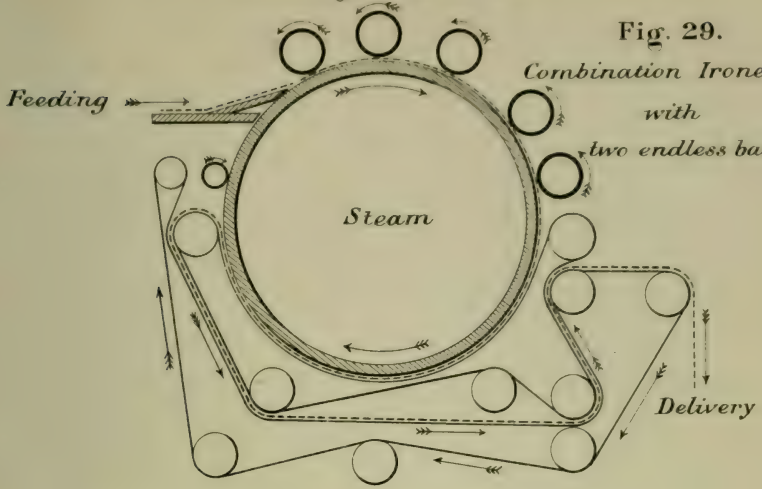


Fig. 30.

Decoudin Ironer combined with stationary drying cylinder.

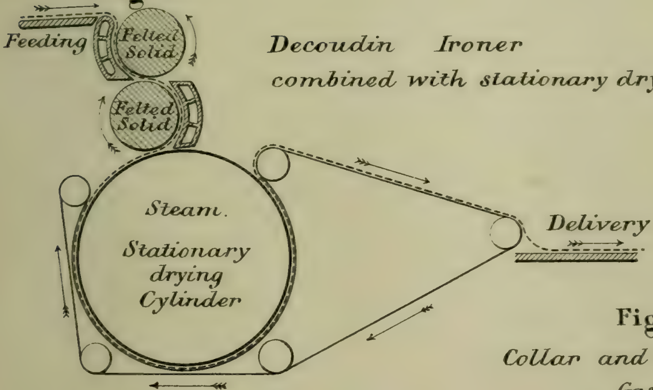


Fig. 32.

Collar and Cuff Ironer.

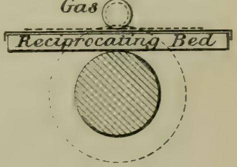
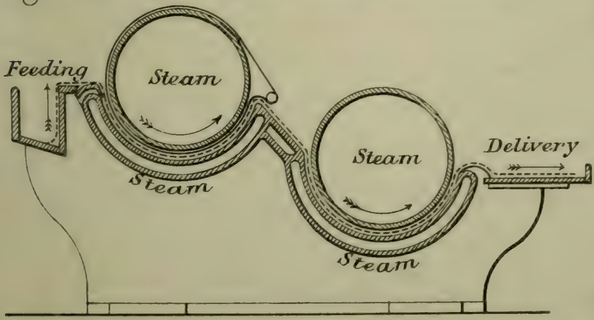


Fig. 31. *Two Decoudin Ironers combined.*



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